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OFFICE OF THE DIRECTOR OF DEFENSE RESEARCH & ENGINEERING
ADVISORY GROUP ON ELECTRON DEVICES

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STATUS REPORT

ON

PROJECTS DEALING WITH

ADVANCED ELECTRON DEVICE TECHNOLOGY

NUMBER 73

FEBRUARY 1963



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Prepared by:
ELECTRON DEVICE GROUP
RESEARCH DIVISION
COLLEGE OF ENGINEERING
NEW YORK UNIVERSITY

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ADVISORY GROUP ON ELECTRON DEVICES

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NUMBER 73

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ON PROJECTS DEALING WITH
ADVANCED ELECTRON DEVICE TECHNOLOGY

Prepared by:
ELECTRON TUBE GROUP
RESEARCH DIVISION, NEW YORK UNIVERSITY
Acting as the Secretariat of the Advisory Group on
Electron Devices under Contract DA36-039 sc-89076

(12)

P R E F A C E

This publication, which is issued bi-monthly by the Advisory Group on Electron Devices, presents in summary form the results being achieved on projects sponsored by the Military Departments and other government agencies in the advanced electron device technology area. Items of collateral interest and extracts from non-government reports and publications will, from time to time, also be included.

While intended to be reasonably comprehensive, the reports should not be considered complete accounts of all work in the area. For the sake of brevity, each item which deals with a continuing project is normally written in serial fashion from report to report; where warranted, a summary review is occasionally included. Individual items appearing in any one issue will reappear in future issues when additional information of a significant nature is available. A file of several issues of the reports is therefore necessary to obtain an over-all view of the program. The information in any report is seldom more than six months old, and every effort is made to keep it as up-to-date as possible.

Unfortunately, the Advisory Group on Electron Devices is not in a position to supply copies of the contract reports for the work described or of publications of other organizations. Requests for government contractors' reports should be made through channels or to ASTIA, and wherever possible, ASTIA document numbers are indicated for the report from which the particular article is derived. Requests for reports on internal projects should be sent to the appropriate laboratories. Reprints of other publications should be requested from the publishers or authors.

For the convenience of librarians who cut out these abstracts in order to file them on index cards, an extra copy of the Status Report will be supplied upon request.

Any suggestions or comments concerning methods by which this report may be made more useful will be appreciated.

TABLE OF CONTENTS

		<u>Page</u>
1.	<u>Government Contracts and Related Projects.</u>	
1.1	<u>Development, Evaluation and Production of Advanced Devices.</u>	
1.1.1	Subminiature, Multilayer, Precision Ceramic Capacitors. Aerovox Corp. DA36-039 sc-87444	1
1.1.2	PEM for Subminiature, Transistor-Type Potentiometers. CTS Corp. DA36-039 sc-85976	1
1.1.3	Ferroelectric Ceramic Filters, If Transformers, and Networks. Clevite Corp. DA36-039 sc-87275	2
1.1.4	Tunable C-Band Reactance Amplifiers. Cutler-Hammer, Inc. (AIL) DA36-039 sc-87405	3
1.1.5	Multi-Turn Metal Film Trimmer Resistors. Daystrom, Inc. DA36-039 sc-86734	5
1.1.6	A Reliable, Long-Life, Planar Triode for a Communications Satellite. General Electric Co. DA36-039 sc-85047	5
1.1.7	PEM on High Perveance Cathode Ray Tubes. General Electric Co. DA36-039 sc-85965	6
1.1.8	PEM: Voltage Tunable Magnetrons. General Electric Co. DA36-039 sc-86722	6
1.1.9	Miniature, Environmentalized, Electrostatic Image Orthicon. General Electric Co. DA36-039 sc-88964	6
1.1.10	Ultra-High-Resolution Cathode-Ray Tube. General Electric Co. DA36-039 sc-90726	7
1.1.11	Advanced Functional Electronic Block. Hughes Aircraft Co. AF33(657)-9771	7
1.1.12	PEM: Type FW-202 Barrier-Grid Storage Tube. ITT Corp. DA36-039 sc-85967	8
1.1.13	Long Life K-Band Magnetron. Microwave Associates DA36-039 sc-87359	8

		<u>Page</u>
1.1.14	High Power Semiconductor Phase Shifting Devices. Microwave Associates, Inc. NObsr-87291	8
1.1.15	PEM on Transistor, Power, 400 Mc, 300 mW. Motorola, Inc. DA36-039 sc-85975	9
1.1.16	Miniature Thin-Film Inductors. Motorola, Inc. NObsr-85397	9
1.1.17	Transistor, VHF, Silicon, Power (25W-100Mc). Pacific Semiconductors, Inc. DA36-039 sc-87342	11
1.1.18	Advanced Television Camera Tubes. Radio Corp. of America AF33(616)-6682	11
1.1.19	High Resolution Camera Tubes. Radio Corp. of America AF33(657)-7939	12
1.1.20	PEM for Tube Type 7587. Radio Corp. of America DA36-039 sc-86732	14
1.1.21	A One-Half Watt Heater Power Reduced-Size Nuvistor Triode. Radio Corp. of America NObsr-81478	14
1.1.22	The Larmotron. S-F-D Laboratories, Inc. AF33(616)-8030	15
1.1.23	Long Life K-Band Coaxial Magnetron. S-F-D Laboratories, Inc. DA36-039 sc-87347	15
1.1.24	Precision, Broadband, Miniature Glass Dielectric Tuning Capacitor. TRW Electronics (Radio Condenser Co.) DA36-039 sc-89083	16
1.1.25	Electron Guns for Intermediate and High-Power Traveling-Wave Tubes. Watkins-Johnson Co. AF33(616)-6441	16
1.1.26	High Resolution Cathode Ray Tube. Westinghouse Electric Corp. AF33(616)-6219	17
1.1.27	High Temperature Match-Box Electron Tubes, Phase II. Westinghouse Electric Corp. DA36-039 sc-87404	18

		<u>Page</u>
1.2	<u>Device Rating, Reliability, Life and Environment Studies.</u>	
1.2.1	The Effects of Nuclear Radiation on Electronic Components: Vol. V - Electron Tubes. Admiral Corp. AF33(616)-7033	20
1.2.2	Combined Environmental Testing of Semiconductor Devices. Burroughs Corp. DA36-039 sc-90766	20
1.2.3	PEM for Improvement of Germanium Alloy Power Transistors. Clevite Corp. DA36-039 sc-86724	21
1.2.4	NF Resistor Factorial Load Life Test. Corning Glass Works NObsr-87385	21
1.2.5	Analysis of Experimental Radiation Effects Data. Edgerton, Germeshausen & Grier, Inc. DA36-039 sc-87306	22
1.2.6	Radiation Effects on Microwave Devices. General Electric Co. DA36-039 sc-87253	23
1.2.7	Basic Radiation Effects Mechanism Study on Electron Tubes. General Electric Co. DA36-039 sc-90735	23
1.2.8	Radiation-Induced Gas Effects on Electron Tube Materials. Radio Corp. of America DA36-039 sc-89121	24
1.2.9	Failure Mechanisms in Ferroelectric and Nonlinear Dielectrics. Raytheon Co. AF30(602)-2678	25
1.2.10	PEM: Reliability Improvement of Silicon Alloy Transistors. Raytheon Co. DA36-039 sc-86744	26
1.2.11	Pulsed Radiation Effects on Microwave Ferrite Duplexers. Sperry Rand Corp. DA36-039 sc-89113	26
1.2.12	PEM To Increase Transistor Reliability. Texas Instruments, Inc. DA36-039 sc-86730	27

1.3 Device Techniques and Studies of Related Phenomena.

1.3.1	A Porous Substrate Resistor Aimed at Miniaturization of Metal-Film Resistors. Daystrom, Inc.	NObsr-87542	28
1.3.2	Submillimeter Wave Component Development. Cutler-Hammer, Inc. (AIL)	AF30(602)-2758	29
1.3.3	Applied Research on Field Emission Cathodes. Field Emission Corp.	DA36-039 sc-90829	29
1.3.4	Application of New Materials and Techniques in Electron Gun Fabrication. General Dynamics/Electronics	NObsr-81208	30
1.3.5	Various Activator-Refractory Substrate Combinations. General Electric Co.	AF19(604)-4093	30
1.3.6	Large-Area Electronic Display Panel. General Electric Co.	DA36-039 sc-90755	30
1.3.7	Field Effect Triodes and Space Charge Limited Triodes. General Electric Co.	DA36-039 sc-90756	31
1.3.8	Improving the Resolution of Iatron Direct View Storage Tubes. ITT Corp.	NObsr-87264	32
1.3.9	Planar Integration of Parts and Solid Circuits into Thin-Film Units. Melpar, Inc.	DA36-039 sc-89109	33
1.3.10	High Power Gaseous Electronics. Microwave Associates, Inc.	DA36-039 sc-89161	34
1.3.11	High Power Transmission Line and Associated Microwave Parts. Microwave Associates, Inc.	NObsr-85455	34
1.3.12	Study of Electrical and Physical Characteristics of Secondary Emitting Surfaces. University of Minnesota	AF33(616)-6239	35
1.3.13	Determination of Dynamics of Electron Emission From Solids as the Result of Impact. University of Minnesota	AF33(657)-8040	36

			<u>Page</u>
1.3.14	Noise Measurements as a Tool in Electron Device Research. University of Minnesota	DA36-039 sc-85289	37
1.3.15	Noise in Semiconductors and Semiconductor Devices. University of Minnesota	DA36-039 sc-85374	38
1.3.16	Metal Oxide Amplifier. Philco Scientific Laboratory	DA36-039 sc-90715	39
1.3.17	Increasing the Sensitivity of Photoemitters. Radio Corp. of America	DA44-009 eng-4913	39
1.3.18	Applied Research in Microminiature Field Emission Tubes. Stanford Research Institute	DA36-039 sc-84526	40
1.3.19	Research on Dielectrics for Microwave Devices. Stanford Research Institute	DA36-039 sc-90856	41
1.3.20	Thin Films Formed by Electrochemical Reactions. Texas Instruments, Inc.	DA36-039 sc-90745	42
1.3.21	PEM: Polyoptic Sealing of Hydrogen Thyratron Tubes. Tung-Sol Electric, Inc.	DA36-039 sc-81289	43
1.3.22	Active Thin Film Circuit Functions. Union Carbide Corp.	DA36-039 sc-90734	44
1.3.23	Interconnection of Functional Electronic Blocks. United Aircraft Corp.	AF33(657)-7890	45
1.3.24	Scan-Conversion Storage Tube Based Upon the Permachon. Westinghouse Electric Corp.	DA36-039 sc-85051	46
1.3.25	Hollow-Cathode Negative-Grid Tube for VHF-UHF Applications. Westinghouse Electric Corp.	DA36-039 sc-90845	47
1.3.26	High Gain Transmission Secondary Emission Films. Westinghouse Electric Corp.	DA44-009 eng-4858	47
1.3.27	Inorganic Binders for "C" Cores. Westinghouse Electric Corp.	NObsr-85304	48

		<u>Page</u>
2.	<u>Publications.</u>	
2.1	Some Semiconductor Surface State Studies. National Bureau of Standards	Report 7746 48
2.2	How Failure Indicators Can Improve Reliability. AF Cambridge Research Laboratories	June 1962 49
3.	<u>Annual Index for 1962: Status Reports 67-72 Inclusive.</u>	
3.1	<u>1962 Annual Index of Government-Sponsored Projects.</u>	49
3.2	<u>1962 Annual Index of Tube or Semiconductor Device Types.</u>	55

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STATUS REPORT NO. 73
ON PROJECTS DEALING WITH
ADVANCED ELECTRON DEVICE TECHNOLOGY

1. Government Contracts and Related Projects.

1.1 Development, Evaluation and Production of Advanced Devices.

1.1.1 Subminiature, Multilayer, Precision Ceramic Capacitors.

Aerovox Corporation

DA36-039 sc-87444

This program was previously reported in S. R. 70. A Final Report has been written. The primary goal of this investigation was to determine whether it is feasible to construct multi-layer Cerafil capacitors with thin dielectric films. Based on favorable data obtained during this work, it is believed that such a feasibility has been established for Cerafil capacitors with three dielectric layers each .0015 in thick. Capacitors so constructed may be safely rated at 30 V at temperatures up to +85°C and at 20 V at temperatures up to +125°C. Capacitors of this type exhibit a capacitance increase of 7-7.5x when compared to standard 100 V Cerafil capacitors of similar size.

The procedure of reducing the particle size of the ceramic materials used for preparing the Cerafil dipping suspensions is a definite aid to producing a more reliable thin film capacitor. Dielectrics fabricated from fine materials are easier to fire to high density because the maturing range is widened by the use of the fine materials and the maturing temperature is somewhat lowered.

The technique of applying the outer electrodes by dipping the dielectrics into a suspension of refractory noble metal before firing is of definite advantage. The last, or outer, ceramic dielectric layer shows less tendency to crack in firing when this technique is employed.

1.1.2 PEM for Subminiature, Transistor-Type Potentiometers.

CTS Corporation

DA36-039 sc-85976

This program was previously reported in S. R. 70. During the fifth quarter of this contract one hundred and forty-four (144) controls were submitted to preliminary preproduction testing to evaluate the modification in design. Test results indicate that the reliability of the unit has been increased by these modifications and the improvements made in the resistance element. Resistance change of over 3% was still noted on the 25,000 cycle rotational life test and the 30 cycle moisture resistance test.

1.1.3 Ferroelectric Ceramic Filters, IF Transformers,
and Networks.

Clevite Corporation

DA36-039 sc-87275

This program was previously reported in S.R.69. Rectangular Uni-Wafer filter blanks were fabricated with up to thirteen 10 Mc dot-resonators. Difficulties initially encountered in electroding and poing the wafers were eliminated by poling the ceramic between parallel brass plates prior to electroding.

It has previously been noted, for various ceramic materials, that considerable anisotropy existed between the radial (lateral expander) mode in which the strain is perpendicular to the direction of polarization and the thickness expander (33) mode where the strain and direction of polarization are parallel. It was also predicted that the thickness shear mode, in which the strain and direction of polarization are again at right angles, should have essentially the same frequency-temperature dependence as the radial mode. This was substantiated by frequency-temperature measurements on thickness expander, thickness shear, and radial resonators in which the resonant frequency varied by 0.52%, 0.22% and 0.16% respectively, over the -40 to +85°C temperature range. As a result, the ceramics developed specifically for temperature stability of the radial mode, i.e., PZT-6A, 6B, can be used to fabricate temperature stable thickness shear resonators. The use of the thickness shear mode should also broaden the operable frequency range of Uni-Wafer devices since its frequency constant is one half that of the thickness expander mode. This would decrease the lower frequency limit to well below the upper frequency limit (6 Mc) of radial resonators. The thickness shear resonators were fabricated from UP 9698 and PZT-6A ceramic that was poled in the plane of the wafer, using a motorized fixture, prior to electroding. Electroless silver appeared to give superior performance on PZT-6A while electroless copper was marginal, however the latter was still satisfactory for UP 9698.

In the measurement of quartz dot-resonator characteristics, the two-capacitor technique has been discarded in favor of the shielded fixture because of the uncertainty in determining the effective capacity at 10 Mc of the added fixed capacitors and the difficulty in obtaining an accurate measurement of the dot-resonator shunt capacity. Room temperature Q measurements (21°C, 60% relative humidity) on a series of dot-resonators yielded the expected values between 40,000 and 50,000.

Quartz Uni-Wafer ladder filters were fabricated at 10 and 20 Mc using the fundamental mode of AT-cut crystals and at 30 Mc utilizing the 3rd harmonic mode of vibration. The latter unit was found to be very sensitive to humidity, a problem which up to the present time had not been evaluated.

The feasibility of quartz Uni-Wafer lattice filters was also demonstrated. Two 10 Mc lattice filters were fabricated with a dot-resonator separation of about $18 \times$ thickness t (compared with at least $36t$ separations on all previous quartz filters). For the first time, effects of interresonator mechanical coupling were observed in the form of excessive pass band ripple and spurious responses in the upper stopband. The spurious responses in the stopband could be reduced markedly by the application of mechanical damping in the region between the resonators. It is anticipated that these spurious responses could be avoided by maintaining a dot-resonator separation of at least 2 ranges of action ($30t$) on all quartz lattice filters. It should be noted that the lattice filter is preferred to study dot-resonator interaction because coupled responses in the stopband produce an effect almost two orders of magnitude greater per resonator than the comparable effect in a ladder filter.

1.1.4 Tunable C-Band Reactance Amplifiers.

Cutler-Hammer, Inc. (AIL) DA36-039 sc-87405

Reactance amplifiers are readily tunable over a 500 Mc bandwidth at 5.5 Gc. Three different types of tuning procedures were demonstrated. The type of tuning that will be used depends solely upon the system in which the reactance amplifiers are used. Since reactance amplifiers usually retrofit existing radar systems, the radar system should be studied to determine the appropriate type of reactance amplifier that should be used. The retrofit should be as simple as possible and should not radically change the existing system. In other words, the reactance amplifier should be designed to be compatible with the existing radar system.

The retrofit of the AN/FPS-16 Monopulse Radar was carried out with a minimum of effort and had negligible effect on the over-all capability of the radar. The amplifiers proved that they were amplitude and phase stable; no radar drift was noticed. The installation was successful.

The retrofit of the UHF amplifier on a receiving radar was also carried out with a minimum of effort and without a major overhaul of the radar. We discovered that a reactance amplifier that is retrofitted into a radar can be successfully remotely tunable.

The silicon pill diode available from Microwave Associates proved to be the most suitable for a tunable amplifier and for the development of an amplifier with a large gain-bandwidth product. The Microwave Associates diode shows a good figure of merit $M = S_1/2-R_D$. This is obtained with a large nonlinearity rather than a high cutoff frequency. It was also shown that the nonlinearity of these diodes has decreased in the past year. Also, it was found that the same type of diode made from different cuttings of the varactor material varied greatly from time to time. This is a serious disadvantage to the circuit designer.

From the information collected under this contract, two distinct recommendations can be made. One concerns the diodes and the other concerns the design of future radars. If the problems concerning the diodes are not quickly solved, the increase in the state of the art of reactance amplifiers could be impaired. Varactor manufacturers should examine their production techniques and determine the changes to their diodes caused by minor variations in production-line techniques. Only by this means will it be possible to control the production of varactors to a high degree of accuracy. The circuit designer can then be assured that the results achieved with some diodes can be duplicated with diodes ordered at a later date.

A standard package for varactors should be considered. At the present time, it is expensive to have test mounts constructed for all packages on the market today. A standard test procedure should also be considered. Each manufacturer uses his own method of testing and specifies the diode parameters as he sees fit. This can be confusing to the amplifier designer.

One method of measuring diodes is covered in this report; another method is to measure the diodes in an amplifier. The degenerate amplifier is the best type for this procedure. From this type of measurement, the figure of merit could be specified together with series resistance, series inductance, and self-resonant frequency. From these parameters, all varactor characteristics could be determined.

With the advent of monopulse radar systems, the phase stability of an rf amplifier must be considered before any retrofit can be undertaken. The broader a reactance amplifier, the more stable its phase characteristic, since the slope of its phase characteristic is not a steep function. For example, the phase characteristic of a 10 Mc wide reactance amplifier is $9^\circ/\text{Mc}$, whereas the phase characteristic of a 100 Mc wide amplifier is only $0.9^\circ/\text{Mc}$. For both monopulse and doppler radars, single-tuned broadband amplifiers are a better choice (because of phase characteristics).

Most radars still use a 30 Mc if; therefore, any advantage gained in phase stability by a broadband amplifier is lost because the image frequency lies within the band pass of the reactance amplifier. It is highly recommended that future radars either be designed with higher intermediate frequencies or use an imageless mixer. For new radars, the former is the better choice. For the retrofit of existing radars with a 30 Mc if, an imageless mixer should be part of the retrofit to permit full advantage to be taken of the characteristics of the reactance amplifier.

1.1.5 Multi-Turn Metal Film Trimmer Resistors.

Daystrom, Inc.

DA36-039 sc-86734

As a result of the work performed during the first quarter of the contract, the following conclusions can be drawn: The Trimmer Resistor as designed per Mil Spec 220978 is applicable to manufacturing and assembly operations on a production basis. An investigation of required tests denotes that test procedures amenable to manufacturing can be developed. The preliminary cost analysis indicates that the unit cost will be comparable to available trimming resistors having similar specifications. The work performed during this period indicates that the schedule for the term of the contract will be held. It is estimated that 15% of the over-all program has been completed. The project in the forthcoming quarter will be accelerated as the task of designing and fabricating tools and starting production processes will be completed.

1.1.6 A Reliable, Long-Life, Planar Triode for a Communications Satellite.

General Electric Company

DA36-039 sc-85047

This program was previously reported in S.R.72. A Final Report has been written. The tube developed as the General Electric Developmental Type Z-5457 meets all of the electrical and mechanical requirements called for under the contract specifications.

Suitable circuitry has been developed which, when using the Z-5457 tube, exceeds the required gain, bandwidth, and power output requirements when operating under the conditions determined as being optimum. Although time did not permit a complete life test evaluation of the tube type to end of life, the data obtained, when projected, indicate a good probability of achieving the objective life.

A system was evolved for selecting from the total production those tubes with the best possibility of achieving the desired life objective. This system was used to select the tubes for application in the satellite system, and to achieve the best combination of materials and processes available, within the time limit, that would produce an optimum product.

The philosophy adopted at the start of the program was proven valid as a means of making a long-life, reliable tube. Use of this philosophy, and the resultant techniques developed, permitted the obligations of the contract to be fulfilled with all deliveries completed on schedule and at a suitable quality level.

1.1.7 PEM on High Perveance Cathode Ray Tubes.

General Electric Company

DA36-039 sc-85965

This program was previously reported in S.R. 70. Experiments aimed at solving the excessive beam-angle and spot-distortion problems provided information and direction for future experiments but no direct solutions to these problems. Some gains in preconvergence technique were made by using a conical suppressor electrode. Until the design problems are worked out and a satisfactory product is evolved, submission of samples will be delayed.

1.1.8 PEM: Voltage Tunable Magnetrons.

General Electric Company

DA36-039 sc-86722

The purpose of this program is a three-phase Production Engineering Measure for Engineering and Manufacturing (Delivery of 14 samples), Production Line Establishment (Delivery of 4 preproduction samples), and a Production Run (Delivery of 50 production packages) of Voltage Tuned Magnetron Types Z-5364 and ZM-6001.

A proposed design for achieving a better vacuum in the tube envelope should result in a tube with less noise.

Improved fixturing of the basic tube and package parts will result in more consistent performance.

Magnet compensation used in the present design will achieve significant reduction of frequency change with temperature extremes.

The proposed design is better designed to meet higher temperature requirements.

The proposed design is improved also with respect to production capabilities.

Life requirements have been demonstrated using a 3-1/2 turn filament.

Minimum power requirements have been achieved in the AM-6001 VTM package using five-vane anodes vs. six-vane anodes used on the DOFL program.

A better tube design will result from the changeover in ceramics from forsterite to alumina.

1.1.9 Miniature, Environmentalized, Electrostatic Image Orthicon.

General Electric Company

DA36-039 sc-88964

This program was previously reported in S.R. 71. A tube with the short return-beam path using a photoconductive target was assembled. This tube produced a 500 TV-line picture by means of the return electron beam and demonstrates the feasibility of these optics. An all-electrostatic image orthicon has been assembled.

1.1.10 Ultra-High-Resolution Cathode-Ray Tube.

General Electric Company

DA36-039 sc-90726

The purpose of this program is to develop and construct a 5 in flying-spot cathode-ray tube for ultra-high resolution. Spot-size requirement: $0.2 \text{ mil} = 5.1 \text{ microns}$. Beam current capability: $10\text{-}15 \mu\text{A}$. Control-sensitivity: $15 \text{ V peak-to-peak}$.

Resolution requirements are theoretically attainable. Beam current specifications can be met only if an emission density of $8\text{-}10 \text{ A/cm}^2$ can be maintained under operating conditions. An alternative approach, using magnetic beam-confinement, is under consideration.

1.1.11 Advanced Functional Electronic Block.

Hughes Aircraft Company

AF33(657)-9771

Part of this contract is to develop the "inductive transistor" into a practical device and use it in micro-resonant circuitry. Attempts in this direction had been made during the summer of 1962. The results indicated that: (1) it is much more difficult than anticipated to control the avalanche multiplication of single transistors in an integrated device; (2) the noise figure and power dissipation are at present too high to compete with ordinary circuits; and (3) the stability of the device, especially as related to temperature changes, is poor.

In the meantime, new progress in field effect devices shows the feasibility of designing active devices with a high input impedance and a high transconductance. This opens the door to providing devices with reactance tube characteristics similar to RC resonant devices.

Comparing reactive devices which use a carrier delay in the semiconductor material versus RC phase shift networks, the following conclusions were reached: (1) Devices using the carrier delay in semiconductors are very temperature unstable and extremely difficult to reproduce. Great progress in the technology is necessary to overcome these difficulties; and (2) RC type networks in combination with high input impedance amplifiers are easier to control with respect to production and temperature stability. They are extremely compatible with the thin film technology.

To build a stable RC-type resonance circuit, an active device with a high input impedance, high transconductance and pentode-like V-I characteristics is necessary. At present an examination is being made of the Si surface channel field effect device which has a high input impedance and may have a sufficiently high transconductance. The question as to whether good pentode-like characteristics are attainable is at present not solved. In case this device does not give the desired characteristic, the use of CdS thin film transistors is planned. These devices are now under study. Further work on the stability factors and the design of improved resonance devices is planned.

1.1.12 PEM: Type FW-202 Barrier-Grid Storage Tube.

ITT Corporation

DA36-039 sc-85967

This program was previously reported in S.R.70. The gun program is essentially complete, but the need for good gargets is holding up final evaluation. The deflection defocusing correction circuits are installed and are working satisfactorily.

1.1.13 Long Life K-Band Magnetron.

Microwave Associates, Inc.

DA36-039 sc-87359

This program was previously reported in S.R.69. Recent work was characterized by success in proving that the isolated anode, rising sun configuration, a basically efficient and rugged design, is capable of at least matching the performance efficiency of a normal magnetron although they have notable design differences. The rarely attempted 26-vane open-ended structure appears to be usable. Information concerning the magnetron's properties was sufficient to warrant turning full attention to the final design.

A tapered magnetic field profile within the electron gun pole cavity has been effected by a new pole laminate method.

Experimental progress on the injection electron gun was slowed considerably by a succession of mechanical failures that prevented acquisition of worthwhile performance data from the beam test apparatus.

Two successive major revisions to the electron gun magnetic circuit have forced a magnet redesign to overcome the higher reluctance paths that were introduced.

The ASDE modulator was modified to operate the proposed tube; a pulse-inverting transformer was designed and adapted; problems of insufficient modulator drive power and corona about the 4PR60 driver tubes appeared overcome.

1.1.14 High Power Semiconductor Phase Shifting Devices.

Microwave Associates, Inc.

NObsr-87291

It was found that an S-band, 3000 Mc, step phase shifter could be built with adjustable phase shift from 0 to 180° with a maximum insertion loss of 0.7 db. Rf power level sustainable was measured at 5 kw peak power at a 0.5 μsec pulse length with an average power of 25 W. No change in the phase shift was noted for power levels from 1 mw to 5 kw. This step phase shifter element could then be used as a building block for multi-step phase shifter having an arbitrary number of binary phase divisions of a full 360°.

The 5 kw peak power rating seems conservative in that the test was made for the value of phase shift which gave a maximum insertion loss and the maximum rf voltage impressed across the diode junctions. Even so the calculated rf voltage appearing across the diodes in the reversed bias state was just equal approximately to their breakdown voltage. Since the diodes were to be used for further evaluation a power test to destruction was not made; although it is believed that the phase shifter could handle considerably more than the 5 kw measured thus far.

An insertion loss resonance effect occurred for a particular value of the position of the sliding short terminating the transmission line in which the diodes were mounted. This was believed to be due to the parasitic inductance of the diode and its mount. Using the known value of series resistance of the diodes in the forward conducting state, 1.5 ohms, and the value of maximum insertion loss obtained, 4.5 db, the value of series inductance was calculated to be either 0.2 or 0.9 nh. A second value was obtained based on measurement of the switching ratio of the diode when used in a similar stripline geometry at 1350 Mc, and from this a value of 0.55 nh was calculated for this series inductance. Considering the geometry of the stripline structure it is believed that the series inductance lies between 0.55 and 0.9 nh, and further effort is intended to define this value more closely. Knowledge of the magnitude of the series inductance of the diode mount used in the phase shifter is useful for obtaining an equivalent circuit for the diode and its mount permitting estimated to be made of the performance that should be obtained for a diode whose parameters are measured by independent methods.

1.1.15 PEM on Transistor, Power, 400 Mc, 300 mW.

Motorola, Inc.

DA36-039 sc-85975

This program was previously reported in S.R. 70. The testing of the pre-production samples has shown that although the 2N2568 is capable of meeting the major electrical characteristics of a specified inspection group, additional effort must be expended to improve the packaging in order that it may exceed the environmental requirements placed upon it.

1.1.16 Miniature Thin-Film Inductors.

Motorola, Inc.

NObsr-85397

This program was previously reported in S.R. 72. A Final Report has been written. Considering inductors with bulk ferrite, in conclusion, using flat spiral coils in combination with two or more bulk ferrite wafers produced a maximum inductance value of 153 μ h with a Q-value of 20 as measured at 1 Mc. The obtaining of larger values of both inductance and Q-value was limited by the following factors:

(a) Initial permeability of the ferrite material was reduced to an effective value of about 50 by an air-gap problem. (b) Surface area and

physical condition of ferrite surface permitted a maximum air-core inductance of 1.6 μ h. (c) A technique of air-gap reduction by fabricating coils in recession in ferrite wafer was not able to be perfected. This was limited by the accuracy to which the required recession in the ferrite could be prepared. (d) Q-values were limited in turn by the affected permeability which reduced total inductance values obtained.

Therefore, if it is desired to obtain larger inductor values using the bulk ferrite approach, the following factors have to be taken into consideration:

(a) Use of larger coils. For example, by increasing the number of turns from 20 to 30, the air-core inductance of the spiral would be increased from 1.6 to 4.1 μ h. This would increase the coil diameter from 0.237 to 0.315 in. Calculations showed that the added turns would not increase the coil resistance to the point where the Q-value of the coil would be affected. It should also be noted that with the use of a larger number of turns, the magnetic path length that is used in the relationship for calculating effective permeability due to air gaps would be increased. This factor would lead to larger values of the effective permeability since the ratio of the gap to the path length would be smaller. (b) Use of ferrite with larger value of initial permeability. This is an obvious choice since the larger the permeability the greater the inductor increase. The reasons for choosing the Stackpole Ceramag 9 for this program have previously been discussed. However, if a ferrite with a permeability of twice that obtained was available, a substantial increase in inductance would result.

In the case of ferrite thin films, a technique has been developed for preparing ferrite thin films which possess properties that are compatible for use with thin spiral coils to provide increases in the air-core inductance of these coils. The films are ferrimagnetic, possess a detectable magnetic moment, are of the ferrite spinel structure, and are formed at a temperature which will allow their use with gold spiral coils.

Initial permeabilities have been measured with values as high as 90 attained. No measurement of film Q-value has as yet been accomplished, but could be done by actual device construction. These films have a density comparable to that of a ceramically formed ferrite of similar composition. The density would seem to indicate that useful Q-values in film material could be obtained.

The composition that has been used for the majority of the work to date is a nickel-zinc-cobalt ferrite. This composition, $\text{Ni}_{0.4}\text{Zn}_{0.573}\text{Co}_{0.027}\text{Fe}_2\text{O}_4$, in bulk form has the desired properties at 1 Mc, i. e., high initial permeability and Q-value.

The main problem encountered to date in the ferrite film program has been controlling the composition of the film as compared to the starting solution composition. The most difficult element to control is the zinc, which has the undesired tendency to be preferentially volatilized in reference to the other constituents. Precise control of the process temperature seems to be the most important parameter in the control of the film composition.

It is recommended to continue this program with emphasis on the use of ferrite films and spiral coils for increase inductance values with practical Q-values. However, bulk ferrite materials should be considered as the supporting substrate upon which the over-all inductor assembly would be processed.

1.1.17 Transistor, VHF, Silicon, Power (25W-100 Mc).

Pacific Semiconductors, Inc. DA36-039 sc-87342

This program was previously reported in S.R.68. The major accomplishment during the third contract quarter has been completion of the design of full scale 25W-100 Mc Transistors and fabrication of sample units using this design that demonstrates the 25 W power output at 100 Mc at 60% collector efficiency and 9 db of power gain.

Process improvement in diffusion and photoresist areas has been achieved with a major effort in the investigation of planar reverse breakdown characteristics. High reverse breakdowns have been achieved but a degradation in subsequent emitter diffusion has warranted further investigation.

100 Mc amplifier circuitry has been redesigned and constructed for testing of full scale units at the required operating test conditions.

Engineering sample transistors for the third shipment were prepared and the electrical performance of the units evaluated. The performance verifies design considerations and the initial samples indicate the required amplifier performance can be achieved.

1.1.18 Advanced Television Camera Tubes.

Radio Corporation of America AF33(616)-6682

This program was previously reported in S.R.62. The Final Report has been written covering the work from June 1959 to December 1961. Advancements were made in the development of a high performance target structure which is consistent with the requirements for a high sensitivity camera tube capable of 1500 television lines/in at 50% sine wave response over a 2x2 in format. Techniques were developed for sealing and firing plug targets which were flat and tight, and suitable for useful resolution tests. Plug targets can produce good pictures with exceptionally low after image. They can be mounted in a manner which is suitable for use and are compatible with S20 photo-surfaces. In the case of enlarged pore targets, a tube containing such a target produced a picture of proper polarity (i.e., the target gain is in excess of one).

In the investigation of the image section, it was demonstrated that without careful design, resolution is degraded in order to maintain faithful geometric reproduction. A method has been demonstrated whereby geometry and resolution may be simultaneously maintained in an image section which has been improperly designed. Sufficient information was accumulated in the course of this work to implement the optimum design for an image section in an advanced television camera tube.

The research on electron beams included a general study, electron energy spectrograph work, a study of the completeness of signal erasure, and the design, construction and study of the performance of positive grid guns. Descriptions of the high resolution camera tube and of the electron energy spectrograph test equipments are included in this report.

1.1.19 High Resolution Camera Tubes.

Radio Corporation of America

AF33(657)-7939

This program was previously reported in S.R. 70. Elements of the effort are being carried out at the Astro-Electronics Division at Princeton, N. J., and the Electron Tube Division at Lancaster, Pa. At Princeton, resolution measurements have been made on an integral-mesh plug-type target image orthicon. Sine-wave response of 50% was obtained at 477 TV lines/in.

A life test program to evaluate cathodes in terms of high performance operating life as well as initial performance has been initiated. Early results indicate that smoothed cathodes on active metal retain their initial resolution properties through at least 200 hours of life test. BN type cathodes improve during this time, and smoothed cathodes on passive metal deteriorate.

Empirical expressions for resolution in terms of beam current, I_b , and the ratio of G_2 current to I_b have been developed. An analysis of the diameter of the electron crossover within the gun from high velocity resolution measurements has been started. A digital computer study of potentials and electron trajectories within the gun structure has begun.

Rate of signal decay and lag were measured for a number of image orthicon targets. Results for low and high capacitance targets were obtained.

Conversion of smoothed cathodes on passive metal in a hydrogen atmosphere was attempted, as was discharge deposition of high-purity inclusion-free aluminum target blanks. Neither of these studies was successful. A hollow-cathode cesium plasma electron gun is to be evaluated for high resolution applications.

A series of new monoscope photographic masters is being prepared which will allow electron gun resolution evaluation over a wider range than previously possible. A 10-tube life test rack has been built and placed in operation for life testing return beam monoscopes. Operation of the Cycled Test Set has been stabilized; non-interlaced scan has been added.

At Lancaster, a variety of schemes have been tried in order to achieve an image orthicon target with high capacitance and high resolution. Desired capacitance is of the order of 500-1000 pF/cm². An integral assembly containing both the charge storage surface and the backplate-collector mesh electrode appears to be the only practical way of achieving such high capacitance.

All approaches have been made using films of aluminum oxide produced by anodizing a sheet of pure aluminum. First attempts were made with solid Al₂O₃ films, but no satisfactory combination of resist and etching procedure could be found. Later efforts have utilized porous anodized films, either in the conducting plug or the enlarged pore approach.

The plug approach involves etching an array of apertures in the oxide film to form a grill of aluminum oxide. One face of this grill is metalized all over as backplate-collector electrode, and metal plugs are placed in the apertures in such a way that they do not contact the backplate-collector electrode. The etching of the aperture array works quite well because the natural pores in the oxide layer are perpendicular to the surface, so that etching proceeds rapidly through the layer pores but slowly parallel to the layer faces. The principal problems have been (1) obtaining aluminum sheet of adequate purity and surface smoothness, (2) obtaining satisfactory plugs none of which short to the backplate and (3) in achieving a sufficiently insulating aluminum oxide in spite of the porous nature of the oxide which tends to adsorb impurities which sometimes produce conductivity.

The enlarged pore approach involves enlarging the natural pores in the aluminum oxide film to a point where it is a very open honeycomb. The backplate-collector electrode is evaporated on at a large angle to the normal to put it only on the projecting edges of the honeycomb. The opposite face has a thin (about 100 Å) continuous film as the storage surface. The principal problems have been the excessive conductivity between backplate-collector electrode and the storage surface, problems of electrical continuity of the backplate-collector electrode and the difficulty of getting sufficient secondary electrons back through the porous structure to the backplate-collector electrode.

In addition, work has progressed on integral mesh plug alumina targets while the effort on enlarged pore targets is being dropped for the present.

A 4-1/2 in image orthicon with a short, single loop of focus image section for best resolution was designed, and an operable tube built with a standard glass target in lieu of the integral plug one. Tests on this tube in the factory test set designed for the longer 2-loop image section were satisfactory. Integral plus targets for this tube are now available. An old laboratory 4-1/2 in test equipment has been partly overhauled to test this tube design.

1.1.20 PEM for Tube Type 7587.

Radio Corporation of America DA36-093 sc-86732

The purpose of this contract is to obtain high volume, low cost manufacturing capability for the Nuvistor tube type 7587 by the creation of several critical equipment facilities. It is an intent of this contract that the subject facilities inherently contain sufficient flexibility to not only service the tetrode line of Nuvistors, but also a broad spectrum of existing triode types and contemplated future types, such as long leaded Nuvistors.

The contract is divided into six phases; namely the development, design, construction, debugging, testing and evaluation of three main tasks: (1) an automatic banded truss grid winding and brazing machine; (2) an automatic exhaust machine; (3) a semi-automatic lead loader.

This effort not only involves the creation and construction of the subject facilities, but a complete in-production evaluation of equipment performance and product quality.

The contract has joint sponsorship, with the development, design and evaluation costs funded by the Army Signal Corps, and the construction costs funded by Radio Corporation of America.

The first 3-month period of this contract was committed, in its entirety, to the development of the engineering concepts necessary for the practical design of the three subject equipments. This phase involved three major areas of effort, namely: (1) liaison with production and tube engineering personnel to determine exact equipment requirements; (2) determination of the methods and mechanisms necessary for satisfying the requirements; and (3) reduction of the concepts to practice by means of experimental devices.

1.1.21 A One-Half Watt Heater Power Reduced-Size Nuvistor Triode.

Radio Corporation of America NObsr-81478

This program was previously reported in S.R. 71. A Final Report has been written. It is believed that the contract requirements have been met and exceeded. These were to produce a triode of nuvistor type construction with electrical characteristics similar to the RCA 7586 but requiring only 1/2 W of heater power, and also to produce a similar but remote cutoff triode. The tubes produced are believed to be superior to their prototypes in some respects. The ceramic-to-metal joint techniques make possible the fabrication of tubes of this extremely small size. They are relatively easy to manufacture, due to the cylindrical cantilever construction used and are readily adaptable to manufacture on nuvistor type production facilities. Their electrical characteristics are obtained with about twice the grid wire diameter,

grid pitch, and interelectrode spacings of planar tubes of equivalent or inferior performance. In addition, the tubes are quite rugged and tolerant of vibration.

The A15274 promises to be an excellent tube for low level, low noise applications from very low to very high frequencies, as well as an excellent low power, stable oscillator at frequencies up to 2.0 Gc.

The A15330 promises to be an excellent tube for a gain controlled rf amplifier required to operate in the presence of interfering signals and also display excellent noise performance at frequencies up to 900 Mc.

Both tubes, due to their ceramic-metal construction, should be even less susceptible to damage and deterioration due to high intensity radiation than are conventional glass envelope types.

1.1.22 The Larmetron.

S-F-D Laboratories, Inc.

AF33(616)-8030

This program was previously reported in S.R. 70. The design has been worked out for a new version of the amplifier using fast wave couplers and a symmetric magnetic lens system for dc pumping. Design considerations in the selection of coupler geometry and gain section design were formulated. Experimental work was done to establish the magnetic circuitry needed for the proper field distribution in the coupler and pump regions.

1.1.23 Long Life K-Band Coaxial Magnetron.

S-F-D Laboratories, Inc.

DA36-039 sc-87347

This program was previously reported in S.R. 72. As a result of the anode evaluation program, it has been possible to improve the Q_u 's by 50-75%. In addition, the high value of Q_u has been maintained over a frequency range greater than that required. Consequently the tube built using the improved anode structure could be tuned to any frequency in the required range with no change in performance.

The last two tubes made operated well on the line type modulator at peak anode voltages within the range of the ASDE-2 system modulator.

Six life test sockets will be required to fulfill the requirements of the contract. S-F-D will build three modulators and will use one ASDE-2 modulator for a life test socket. It is expected that the FAA will supply two field sockets for 24-hour-per-day operation.

The requirement of a 5000 hour life for the 24 Gc ICEM coaxial magnetron seems consistent with results obtained to date at Ka-band. This Ka-band tube operating at twice the power level, 25x the pulse length, and with smaller anode and cathode surface area has operated to date for 3700 hours with no measurable degradation in performance.

1.1.24 Precision, Broad-Band, Miniature Glass Dielectric
Tuning Capacitor.

TRW Electronics
(Radio Condenser Co.)

DA36-039 sc-89083

The purpose of this project is the development of a miniature tuning capacitor, covering 3-8 Mc in one band, employing novel "thin glass dielectric" designs. The tuning capacitor shall be stable with respect to time and temperature over a temperature range of -55°C to $+125^{\circ}\text{C}$, and shall not be significantly affected by high humidity, and mechanical shock and vibration environments.

It is necessary to obtain thin glass ribbon, having suitable electrical, physical and dimensional properties and to arrive at a method of accurately producing predetermined metal configurations on the surface of thin glass ribbon.

A design of a variable capacitor will be formulated using the glass ribbon and metallization techniques stated above, that will achieve the purpose of the project.

Glass ribbon of correct electrical and physical properties must be secured. The available Corning #8871 was too thin and fragile. The Corning Type #0211 had low K and Q characteristics.

The metallization process tried was unsatisfactory. The metal-to-glass bond was poor, resulting in soldering and electroplating difficulties. A metallization process other than the evaporated deposition method will have to be employed. Heat fusion methods presently employed in metal-to-glass seals are promising. As previously stated, suitable glass ribbon will have to be obtained, so coefficients of expansion and melting temperatures can be established, in order to proceed with the metallization efforts.

1.1.25 Electron Guns for Intermediate and High-Power
Traveling-Wave Tubes.

Watkins-Johnson Company

AF33(616)-6441

This program was previously reported in S.R.63. A Final Report has been written. Two new techniques have been developed which have resulted in marked improvements in high convergence guns of high perveance. The most important of these methods involves properly shaping the cathode surface. The use of a multi-electrode structure for the usual focus electrode to optimize the beam edge potential has also materially aided the design of high convergence guns. The use of these two methods has resulted in a number of gun designs which are fully described. One of these has a 300:1 area convergence at a perveance of 2.2×10^{-6} . These guns, including the latter one, have been thoroughly analyzed and have been successfully focused

(greater than 99% beam transmission) in sealed off drift tube beam testers. Although extreme care must be exercised in the focusing of very high convergence beams, the practicality of this design approach has been demonstrated.

A simple, easy-to-use, demountable beam analyzer has been developed which provides accurate measurements of the current density and radial velocity content in the resulting beams. This device uses a Vac-Ion pump which does not require cold trapping.

There is little doubt that the techniques described here can be extended to even higher convergence ratios and perveance values. It is recommended that further investigation, particularly with regard to cathode shaping, be supported.

1.1.26 High Resolution Cathode Ray Tube.

Westinghouse Electric Corp.

AF33(616)-6219

This program was previously reported in S.R. 63. A Final Report has been written and it describes the general design and the construction details of a 5-in diameter ultra high resolution CRT yielding a spot of .0005-in diameter at the half-power points with a beam current of 5 uA.

It is shown that the performance achieved is almost certainly being limited by aberrations in the final lens system and/or by the screen gain structure. There is reason to feel that a spot diameter of about 0.2 mil may be obtainable simply by substituting an evaporated phosphor and a larger final lens system.

It discusses the design of elaborate test equipment, using the principle of slit scanning, to measure these spot sizes accurately.

The report develops a general theory of narrow angle cathode ray tube design which is applicable to any similar problem.

This theory is applied to study the limitations in cathode ray tube performance set by the maximum permissible cathode loading, by the beam space charge, by deflection defocusing, and by constructional difficulties.

It is concluded that further progress will be very difficult. However, the only ultimate limit is set by diffraction which defines a limiting spot size two or three orders of magnitude below that yet actually achieved.

1.1.27 High Temperature Match-Box Electron Tubes, Phase II.

Westinghouse Electric Corp.

DA36-039 sc-87404

This program was previously reported in S.R. 71. A Final Report has been written. It has been demonstrated that an electron tube (triode) can operate in a Pyrocera 9606 envelope using a #45 solder glass seal. It was necessary to design a new type of triode. An unusual tensioning system and a novel cathode support were devised. Nickel was shown to be an excellent high-temperature external lead. In addition, a new type of frame grid was made and the tube was sealed and partially processed in an argon atmosphere. Yet despite all these innovations, three basic weaknesses in the tube were apparent. One was oxidation of the exposed edge of the tungsten ribbons, which caused the ultimate seal failure some time after 500 hours during the 400°C life test. This also caused one out of four tubes to fail the moisture resistance test. These edges could have been protected by solder glass with some changes in the design of the tubes.

The second weakness was the susceptibility of the solder glass #45 to nuclear-radiation damage. This is inherent in the solder glass composition. It is interesting to note that this was not observed in the Phase I investigation despite the fact that the radiation exposure was about 100x more intense. This can be explained, however, because the broad, tungsten ribbons sealed in the match-box triode would be more susceptible to leaking with an expansion mismatch than would the 0.030 diameter wire leads used in the Phase I investigation. Furthermore, the operating triode would be more sensitive to leaks than would an empty shell.

The third weakness was in the grid design, which made the grid temperature so sensitive to the external ambient temperature. If the grid had been designed to let the lateral wires run hotter, the grid would not have been as susceptible to contact potential changes at higher ambient temperatures. Thus the tube would have been more stable.

Aside from these problems, the tubes withstood the vibration, shock, and fatigue tests quite well. For a first model of a new design, the results were very encouraging. However, the most important fact is that a tube could be made to operate in a Pyrocera 9606 envelope.

Using Pyrocera as a tube envelope material, tubes of different designs could be assembled with solder glass, brazing techniques, or combinations of both. Tests were conducted on brazed Pyrocera envelope assemblies, and although some difficulties were encountered none of them were insurmountable. The major disadvantage of using Pyrocera 9606 instead of alumina, for example, is that this Pyrocera reacts with hydrogen at elevated temperatures. Thus the metallizing and brazing must be done in a vacuum or in an inert atmosphere requiring cumbersome and expensive assembly methods instead of a simple hydrogen furnace.

Nevertheless there are features of Pyroceram 9606 that make it desirable in some cases. These special features are a lower coefficient of expansion and a lower dielectric constant. Another desirable property of Pyroceram could be low cost. It is believed that in large quantities, precision Pyroceram parts could be obtained cheaper than their alumina equivalents. This would be because Pyroceram can be molded in glass-making machinery and can be precision ground in its glassy state prior to devitrification. These automatic techniques when used in large volume are inherently more economical than the batch process used in alumina ceramic fabrication.

The solder glass is unique with its thermal-setting insulating properties. It has certain disadvantages. It is subject to attack by heated acetic acid. It is weakened by nuclear radiation. Furthermore, it requires a long, elaborate sealing cycle. Nevertheless it has no competitor as a high temperature setting cement, and it offers opportunities to build structures that were not previously possible. An example of this is the triode described previously. Another example would be a stacked tube. In a brazed stacked assembly, each element is connected to a disk that is brazed in place. By using solder glass, however, each element could be connected to a ribbon that passes out through a single solder glass seal. Thus several leads could protrude through one seal and interelectrode capacities could be reduced.

Another prospect might be to build solder-glass subassemblies using a brazed joint as a final seal. A high-temperature stem could be made using Pyroceram. The leads would consist of a nickel outer lead, butt-welded to a tungsten inner lead. The weld knot could be imbedded in solder glass in an appropriate place in the Pyroceram stem. By proper choice of brazing alloys, this stem could subsequently be brazed in place.

Pyroceram and the associated solder glass are still relatively new materials and there are still many things to be learned about them. Of particular interest is the recent development of a new form of Pyroceram that is hydrogen inert. This material can be metallized by the moly-manganese technique in a hydrogen furnace and subsequently brazed in a hydrogen furnace. This would permit a more convenient, cheaper assembly than would be possible using Pyroceram 9606.

It is believed that this material should be investigated and fully evaluated as a possible substitute for alumina ceramics in stacked types of tubes. Should the demand for a large volume of ceramic tubes evolve, the potential low cost of Pyroceram parts would be extremely important.

1.2 Device Rating, Reliability, Life and Environment Studies.

1.2.1 The Effects of Nuclear Radiation on Electronic Components: Vol. V - Electron Tubes.

Admiral Corporation

AF33(616)-7033

The report presents data concerning the effects of a nuclear environment on several types of special purpose tubes. The types evaluated were 5727/2D21W thyratrons, BL800A klystrons, 3E29 dual tetrodes, 3CX100A5 ceramic hi-mu (UHF) triodes, and 3D21B pulsed modulator pentodes. All of the tubes were exposed to an average integrated fast neutron flux of at least 1×10^{16} n/cm² and gamma doses of 4.5×10^{10} ergs gram⁻¹(C). Several units of each type evaluated were enclosed in cadmium to reduce the thermal neutron exposures. All of the 3E29 dual tetrodes without cadmium shielding suffered glass envelope fractures. All of the BL800A reflex klystrons survived the irradiation period. One of the 5727/2D21W thyratrons failed to ionize after approximately 160 hours of operation in the reactor; all other units operated normally. All of the 3D21B pulsed modulators and the 3CX100A5 ceramic hi-mu (UHF) triodes survived.

1.2.2 Combined Environmental Testing of Semiconductor Devices.

Burroughs Corporation

DA36-039 sc-90766

The object of this study is to ascertain whether the combined environmental effects of temperature and pulsed nuclear (gamma and neutron) radiation on semiconductor devices are simply the sum of the two single effects or a complex interaction of the two. A statistical sample of four major device categories (two silicon and two germanium) will be exposed at various temperatures to various intensities of radiation pulses. The resulting transient, long term recovery and permanent effects will be recorded. The data will be analyzed to determine the degree and modes of interaction of the different environmental effects. A theoretical explanation will be formulated to account for the observed phenomena. The concepts evolved in this study will broaden the understanding of the basic mechanisms of radiation damage on semiconductor devices. This will assist in developing techniques for the control or elimination of device degradation, which in turn will facilitate the design of electronic hardware capable of reliable operation in such combined hyperenvironments.

The task may be divided into the following phases: (1) Design; (2) Fabrication; (3) Checkout; (4) Data Collection; and (5) Evaluation.

The first quarter was primarily concerned with designing, planning and preparing for the actual tests, which will be conducted later. Conclusions directly related to the program objectives can only be made after this time. However, in reviewing the available information on pulsed nuclear radiation testing it can be concluded that the techniques presently employed in obtaining transient radiation effects information are not yet adequately developed.

Information available on the effects of pulsed radiation on telemetry cables and on sample fixtures indicates that the uncontrollable and undeterminable presence of these detrimental effects can mask the effects being sought. Previous studies have not been able to give ample consideration to the significance of slight cable geometry variations, the use of balanced lines, and polarizing voltages to control or minimize these effects.

Accordingly, in order to record information of the accuracy and reliability required to achieve the desired objectives of this program, a greater effort should be directed toward proving the validity of the approaches planned for the forthcoming test.

1.2.3 PEM for Improvement of Germanium Alloy Power Transistors.

Clevite Corporation

DA36-039 sc-86724

This program aims at improvement of production techniques to increase the reliability for the transistors. This shall include all work necessary to establish capacity to manufacture the specified transistors utilizing the improved production techniques including all quantities of samples to be delivered, actual modification of production equipment to incorporate the improved technique, performance of the necessary tests to demonstrate the capability of the improved production line and the preparation and distribution of the reports.

Germanium Alloy Transistor types 2N297A, 2N1011 or 2N1120 with a maximum operating failure rate of .05 per cent/1000 hr at a 90 per cent confidence level at 25°C as an objective. The failure rate is an objective and as a minimum the following improvements will be performed: (a) Cleaning Procedure; (b) Surface Passivation by Oxidation; (c) Surface Passivation by Organic Coats; (d) Novel Method of Alloying; (e) Increase in Emitter Efficiency; (f) Hermeticity.

1.2.4 NF Resistor Factorial Load Life Test.

Corning Glass Works

NObSr-87385

This program was previously reported in S.R. 72. The major portion of recent effort was expended toward completion of activities leading up to installation of mounted and wired test boards in the ovens.

The test circuit was altered to obtain faster component delivery and to afford increased circuit reliability and considerable effort was also expended in providing proper processing procedures and in setting the resistor measurement equipment in good order.

The 10,000 hour test was started and approximately 500 hours of test time was accumulated on the resistors.

1.2.5 Analysis of Experimental Radiation Effects Data.

Edgerton, Germeshausen & Grier, Inc.

DA36-039 sc-87306

This program was previously reported in S.R.70. A Final Report has been written.

Based on analysis of the experimental data reduced and on the empirical and theoretical consideration of the effects of radiation on semiconductor devices, the phenomenological expressions developed give the best possible predictable description of I_{CO} and H_{FE} that can be drawn from the available evidence. However, since a complete computer program has not been run to test the final expression, and in view of the gap in positive time-tie information and spurious signal contributions, semiconductor device response cannot be characterized emphatically at this time. However, on the basis of the analysis evolved and presupposing a more precise delineation of the nuclear reactor environments and of the device characteristics, it appears that an expression can be derived that would allow prediction of the behavior of semiconductors exposed to any radiation environment. While a considerable effort would be required to obtain an "all encompassing" expression, the program just concluded indicates that a "practical" solution is within reach.

On the basis of the analysis program just concluded, it is recommended that the quasi-theoretical development evolved be applied to other tests of complete devices to substantiate its validity in predicting the response mechanism of such devices as exhibited by experimental evidence. In addition to working towards a further refinement of the expression for I_{CO} and for H_{FE} , it is further recommended that in future programs investigating the behavior of semiconductor devices in a radiation environment, the analysis program be undertaken conjointly with the design-of-experiment study.

Since the useful information from any experiment is only that incontrovertible data extracted from the experiment, the person or persons charged with the analysis must be consulted in the design of the experiment and have some control over the instrumentation used and over the experimental plan followed. In this light, it is suggested that such future radiation experiments as are undertaken utilize high speed oscilloscopes in conjunction with magnetic tapes as recording media. Since oscilloscopes can give precise definition of high density information signals at very short time intervals, and magnetic tapes provide long duration data,

the combination of recording techniques would result in complete records on such events, particularly if the instrumentation incorporates accurate time-tie information throughout. While such instrumentation would involve additional costs, it is felt that the results would more than justify the additional expense.

Recommendation is also made that further study (or studies) be made such that state-of-the-art knowledge be advanced to the point where a definitive answer on the suitability of employment of a particular semiconductor in a particular radiation environment (of any nature) be possible on the basis of both quantitative and qualitative information. The increased use of such devices and concern with exotic environments makes this a logical outgrowth.

1.2.6 Radiation Effects on Microwave Devices.

General Electric Company

DA36-039 sc-87253

This program was previously reported in S.R. 72. The activity of the program is divided into two tasks:

Task 1 - Study of Radiation Effects on Voltage-Tunable Magnetrons. This task will be a continuation of the work currently in progress, in which the operational behavior of voltage-tunable magnetrons (VTM) in a pulsed radiation environment is observed and recorded. Work within this task will be directed toward the development and delivery of a radiation-resistant device.

Task 2 - Study of Radiation Effects on Traveling-Wave Tubes. This task is an extension of the project, in that the traveling-wave tubes (TWT) have not been subjected to radiation evaluation during this program. Emphasis will be placed on the investigation of TWT parameter behavior in a pulsed radiation environment. A literature search will be conducted on materials and techniques pertinent to this task. All information and evaluation will be directed toward design considerations for a radiation-resistant TWT.

Task 2 has been in operation since September 1962, and no conclusions have yet been drawn.

1.2.7 Basic Radiation Effects Mechanism Study on Electron Tubes.

General Electric Company

DA36-039 sc-90735

The purpose of the program is to determine the basic mechanisms causing transient changes in operating characteristics of electron tubes in a pulse of nuclear radiation. Phase I consists of a search of all known technical literature on this subject. Phase II involves the design and experimentation. Tube materials and structures will be exposed to various simulated nuclear explosions. Phase III involves analysis and evaluation of the data. When the over-all

program is completed it is hoped that sufficient data will be obtained to enable tube manufacturers to design and develop components that are insensitive to nuclear radiation. This is of immediate and practical interest if modern military communications and weapons systems are to perform reliably in a nuclear radiation environment.

In the first quarter of work the basic mechanisms which cause transient changes in the operating characteristics of electron tubes in a pulse of nuclear radiation were studied. A literature search was conducted to learn the state of the art, order of magnitude calculations have been initiated to predict dominant reactions and experimental tests will be conducted to study the effects.

The literature survey and preliminary calculations indicate that the production of Compton electrons is the primary cause of transient effects. In order to get valuable experimental results, dummy cables and specially designed support ceramics were used to reduce cable effects and leakage. Potting of exposed leads will reduce air ionization effects. Reliable data in the literature points to increased dielectric conductivity and the ejection of electrons from surfaces as the primary causes of changes in the operating characteristics of electron tubes.

1.2.8 Radiation-Induced Gas Effects on Electron Tube Materials.

Radio Corporation of America DA36-039 sc-89121

This program was previously reported in S.R. 71. A Final Report has been written. Numerous electron devices have been developed to purposely exhibit a transient effect when exposed to radiation through gas ionization. Such devices are most generally of a radiation detecting nature. Other studies have shown that various glasses evolve gas or permit the diffusion of gases when exposed to high intensity nuclear environments. Further, an incidence of failure in electronic circuits exposed to radiation environments is a matter of record. These failures occurred where vital components were not potted in materials that would exclude air, which when ionized under radiation, caused transient operation.

On the basis of this background knowledge, it was assumed that gases could be evolved from the walls or components of vacuum tubes, operating in or intermittently exposed to a radioactive environment. These gases, in turn, could either ionize or temporarily poison the cathode causing an electronic transient to occur. This study was accordingly undertaken to determine if indeed such radiation induced gas effects occurred in electron tubes, upon either steady rate, or pulsed radiation exposure.

Prior to stating the conclusions reached as a result of the study, it must be pointed out that the use of cryogenic pumping in collecting gases, although by far the most effective method available, exhibits certain

limitations. The first is an inability to collect quantities of less than 5×10^{-7} liter-mm. The second limitation is the establishment of a gas ambient, caused by the necessity to continue cryogenic pumping during the period the tube was operating, rather than coincident to the radiation exposure. The effect of this ambient gas level could be of important significance to the test results. If the gases evolved during the radiation pulse are the same as the ambient, a level of 2 or 3 orders of magnitude higher than the above minimum (5×10^{-7} liter-mm) would be required for significant measurement.

The conclusions reached as a result of this study are as follows:

- (1) Electron tube materials were found to evolve gas under the influence of steady state radiation. This evolved gas was shown to be due to thermal outgassing under the influence of gamma heating.
- (2) Within the limitations imposed by the cryogenic system, electron-tube materials and electron tubes showed no gas evolution when exposed to high intensity pulsed radiation. (Sandia Pulsed Radiation Facility)
- (3) Although both tube types in this investigation showed transient effects, the 7586 triode nuvistor showed a lesser transient of shorter duration than did the 7457 power tetrode. This implies that a device of lesser volume, irrespective of gas effects, showed greater stability to the radiation field. This observation may have significance when designing electronic equipment which must experience nuclear radiation. As a result of this study, no new limitations to small ceramic electron tube design are indicated.
- (4) Radiation induced gas is not a significant mechanism of the deterioration observed in the electrical characteristics of small ceramic tubes.
- (5) Further investigation is warranted to explain deterioration effects by nuclear radiation in terms of (a) grid emission, (b) photon emission, and (c) impedance changes.

1.2.9 Failure Mechanisms in Ferroelectric and Nonlinear Dielectrics.

Raytheon Company

AF30(602)-2678

The object of the "Physics of Failure" studies is to seek the answer to the question, in a fundamental way, of how any operating system, component or material ceases to operate. By this means it is hoped that device reliability can be optimized by systematic application of the fundamental knowledge concerning failure mechanisms. Furthermore, reliability information obtained in one application may be extrapolated to another context.

The emphasis in this approach lies upon understanding of the fundamental mechanisms of failure. In ferroelectric and nonlinear dielectric devices it appears that the basic reasons for failure are connected with electrical breakdown, conductivity, phase stability, surface effects, and the electro-mechanical properties.

The studies which have been undertaken are aimed at understanding these effects and the influence upon them of temperature, material preparation, and their environmental conditions.

In early work, the electrical conductivity of SrTiO_3 has been measured by dc and microwave techniques. Pure, doped, and oxygen deficient material were studied and the temperature dependence of the conductivity was observed. Activation energies in the pure materials and mobilities in the oxygen deficient materials have been measured. Preliminary studies of the breakdown voltages in pure SrTiO_3 showed bulk breakdown strengths of 10^6 v/cm. The temperature dependence of the electrostrictive constant g_{31} has been studied in the paraelectric temperature range for pure single crystal SrTiO_3 . Annealing procedures have been developed for the strain-relief of flame fusion grown SrTiO_3 boules.

1.2.10 PEM: Reliability Improvement of Silicon Alloy Transistors.

Raytheon Company

DA36-039 sc-86744

The purpose of this Production Engineering Measure is to institute process and design changes to improve the reliability of Silicon Alloy Transistors. The necessary capability to manufacture the specified transistor utilizing the improved production techniques will be established and proof of the reliability achievement given.

Process changes concerning the materials areas and stem configuration were made and appropriate Quality Control measures introduced. Polysiloxane thin films were investigated and it was decided to discontinue further work on this approach. A temperature step-stress experiment was made to obtain an indication of reliability direction. A second experiment concerned etching in an attempt to optimize the junctions.

1.2.11 Pulsed Radiation Effects on Microwave Ferrite Duplexers.

Sperry Rand Corporation

DA36-039 sc-89113

The general purpose of this study is to determine the effects of pulsed nuclear radiation on the operating characteristics of C-band beacon ferrite duplexers wherein the components used to make up the duplexer are two C-band microwave coaxial ferrite Y-junction circulators and one gyromagnetic coupling limiter. The ferrite duplexer to be investigated was developed by Sperry Microwave Electronics Co. under Contract DA36-039 sc-85330. Experimental radiation effects data are to be acquired for the duplexer and/or its components operating in a frequency range of 5.4 to 5.9 Gc and, initially, for an operating power level (at the klystron) of approximately 1 watt (considered low power operation).

Specifically, the aims of the first quarter of the study were the following:

- (1) The initiation of a brief survey of applicable literature describing previous experimental and theoretical work concerned with pulsed nuclear radiation effects on solid state ferrite devices;
- (2) A limited investigation of the theoretical methods available for describing potential radiation induced damage mechanisms; and
- (3) The design and testing of appropriate circuits to be used in monitoring duplexer component performance during exposure to the nuclear radiation environment.

Subsequent phases of this study are presently visualized for determining methods of improving component and duplexer performance in a radiation environment and then applying these methods in the development of "radiation-resistant" components and duplexers.

The results of the literature survey indicate that the following principal failure mechanisms may be observed in the components: (1) the rate or transient effect due to γ -ray induced ionization, and (2) the formation of vacancies and interstitials within the highly ordered ferrite and garnet lattices due to integral doses of fast neutrons.

The mock-up experiments conducted at SMEC indicate that a signal amplitude problem exists at the recorder input. This problem can be compensated for by the use of a dc amplifier; however, the calculated rise time of the amplifier and recorder indicate that the signal characteristics will be somewhat distorted during the initial 5 to 10 μ sec.

Experimental tests were devices for a test series. Pending the results of these tests no definite conclusions as to radiation effects on the C-band Y-circulators, isolators and gyromagnetic-coupling limiters can be made.

1.2.12 PEM To Increase Transistor Reliability.

Texas Instruments, Inc.

DA36-039 sc-86730

The purpose of this program is to establish engineering measures necessary for attainment of a maximum operating failure rate of .01 per cent/1000 hr and .001 per cent/1000 hr at a 90 per cent confidence level on the 2N960 series of germanium epitaxial mesa transistors, and the 2N744 silicon non-planar epitaxial transistor, respectively.

Early work shows that for the 2N964, the quality of the epitaxial material is quite good. However, continued efforts are required for additional refinements in control of resistivity and thickness.

Diffusion control is excellent. The change from powdered dopant to pellet form should take place smoothly.

Work on cleaning techniques has been carried out only at the pre-can stage. Further work must be done here as well as at other stages; i.e., pre-evaporation, mesa masking, wafer sorting, etc.

The feasibility work on mesa and die cutting has progressed slowly due to mechanical problems.

For the 2N744, the reason for "on time" failures has been determined and corrective measures incorporated into the process. A method has been proposed for measurement of N on N+ epitaxial layer resistivity. Additional study will be required to perfect this method. Promising results have been obtained using metal-gold contact combinations. Additional work is required in this area. Nickel-gold header plating has been replaced with "duplex gold" header plating, which increases the mechanical strength of the device. New boron and phosphorus diffusion processes are being developed which will give more consistent and controllable results. Work is under way to improve the photomasking and oxide etching operations. Efforts will continue in this area.

1.3 Device Techniques and Studies of Related Phenomena.

1.3.1 A Porous Substrate Resistor Aimed at Miniaturization of Metal-Film Resistors.

Daystrom, Inc.

NObsr-87542

The purpose of Phase I is to conduct a study of techniques and processes to determine the capability of Weston's proprietary chemical deposition process for producing metal film resistors on porous substrates. The study shall be directed toward the determination of the feasibility of using this process in developing an accurate, precision, metal film resistive element which can be adaptable to micro-miniature circuits. Such techniques as chemical deposition, etching, markings, etc., shall be investigated. Chemical concentrates, metallizing cycles, curing cycles, and other factors shall be determined. The effects of these factors on the resistivity per square, temperature coefficient and stability shall be determined.

Numerous vendors have been contacted as to availability of porous materials which were sought in the area of plastics as well as glass and ceramics.

Various techniques for film deposition have been tested, and various substrates, meeting necessary temperature and electrical properties, were tested for acceptance of film deposition. Acceptable deposition has been obtained on several samples which include porous substrate and glass spheres.

Film deposition has been accomplished using normal chemical concentrations and tests have indicated that the minimum pore size necessary for uniform deposition will be 25 microns.

1.3.2 Submillimeter Wave Component Development.

Cutler-Hammer, Inc. (AIL)

AF30(602)-2758

Techniques for the design, construction, and evaluation of a 10 db directional coupler, a 0-40 db variable attenuator, a 90° phase shifter, and a duplexer to operate in the 300-1000 Gc region were investigated theoretically and experimentally. Quasi-optical techniques, oversize-waveguide, trough-guide, and Goubau beam guide were studied. Quasi-optical techniques used in oversize waveguide were emphasized for the development of components. Detailed theoretical analyses of this technique have been made, and component design data was recorded. A generation and detection system using a harmonic generator has been designed and is being constructed to provide a means of testing at submillimeter frequencies. Construction of many components such as tapers and adapters was necessary because these items were not commercially available.

1.3.3 Applied Research on Field Emission Cathodes.

Field Emission Corporation

DA36-039 sc-90829

This program is an extension of work performed by Linfield Research Institute under DA36-039 sc-85368 which was previously reported in S.R.71.

Electron micrographs of the individual field emitters of tungsten multiple-needle array cathodes following recrystallization by heating to 2750°C for 10 min in hydrogen indicate nearly complete absence of grain boundaries. Cathode uniformity and performance is expected to be greatly improved through use of this treatment. Studies of array type cathodes fabricated from thoriated tungsten show promise; however, better control of thorium coating uniformity will be required before the potential advantages of such cathodes can be realized. The effect on beam divergence of array geometry for a double row array was studied by means of the electrolytic trough. The limiting emitted current as a function of emitter cone angle and terminal radius was studied for tungsten single needles during pulsed operation with a pulse length very long compared to the thermal time constants for the emitter tips.

The focusing properties of the most recent electrostatic lens design were studied by means of the electrolytic wedge analogue using an axially centered circular array of field emitters as cathode. Earlier data on an experimental comparison of two electrostatic lens designs was verified; and an experimental study of the magnetic focusing of emission from a zirconium-coated tungsten field emitter was begun.

Life test programs for study of cold field emission cathodes in tubes operated at increased average power and of the life terminating mechanisms of T-F cathodes were initiated.

Problems associated with improvement of the purity and mechanical properties of field emitters fabricated from refractory metallic compounds are under consideration. Quantitative data were obtained concerning the surface diffusion of zirconium on a tungsten substrate and the variation of work function of zirconium-on-tungsten surfaces as a function of temperature. Behavior of hafnium on tungsten was shown to be superficially similar to zirconium on tungsten.

Apparatus has been constructed for a study of the gas-phase micro-machining of emitter tips in iodine vapor. Highly purified iodine samples have been prepared and gas-phase oxidation experiments on tungsten emitters are being initiated.

1.3.4 Application of New Materials and Techniques in
Electron Gun Fabrication.

General Dynamics/Electronics

NObsr-81208

This program was previously reported in S.R. 70. Phase III is considered complete although the various difficulties encountered precluded the delivery of finished tubes. Parts delivery has seriously delayed the initiation of the life test but the difficulties have been resolved and tubes were scheduled to be put on the life test about the end of November 1962.

1.3.5 Various Activator-Refractory Substrate Combinations.

General Electric Company

AF19(604)-4093

This program was previously reported in S.R. 66. A study has been made of the electron emission behavior and other important properties of new combinations of materials that have potential interest as cathodes in electron tubes. This information and the experimental techniques are also of interest in the field of thermionic energy conversion. As of 31 January 1962, Contract No. AF19(604)-4093 has been terminated and future work will be continued under Contract No. AF19(628)-279. A final report covering the entire investigation will be forthcoming at a later date.

1.3.6 Large-Area Electronic Display Panel.

General Electric Company

DA36-039 sc-90755

The work to be performed during the contract is directed to advancing the state of the art of large-area electronic display. Prime interest is placed on achievement of high resolution images which may be comfortably viewed under conditions of high ambient illumination.

The selected approach consists of an electron-beam writing on a thermoplastic film with a novel optical projection system. Development work is generally divided into two categories, electron-beam writing and optical projection.

The role of the first quarter was given to planning the project organization and technical approach; and to initiate that approach. From the present position in the project it has been concluded that the initial project organization, thus far, is sound.

Initial work with the TIRP projection system leads one to believe that the brightness requirements will be met. No statements are possible as yet regarding the resolution capabilities of the TIRP projection objective, since that issue is tied to the success of an associated company-funded program. Work is progressing, but it is not presently possible to predict the quality of the first delivered TIRP projection objective. It appears that the lamphouse and Model A TIRP projection objective will be completed shortly.

The initial work with the Model A TIRP projection objective and the expected delay in delivery of the TIRP projection objective dictates that a solid Schmidt TIRP objective be investigated. Following the design phase, a solid Schmidt TIRP projection objective will be built and evaluated.

The initial work on the modified Gleichauf electron-gun has shown the real worth of the Gleichauf electron-optical concept of accomplishing electron-beam deflection within the same volume in which the electrostatic focusing takes place. R. B. Gethmann has extended this concept to show the real potential offered, that is, produce an extended deflection electron-optical image with uniform focus. It has been shown that the above aberration-balancing approach is valid and that its potential is so great that all other electron-optic approaches, such as the all-magnetic deflection electron gun will be dropped from further consideration. Work will now be directed toward designing and building a new electron gun that utilizes the aberration balancing principle.

1.3.7 Field Effect Triodes and Space Charge Limited Triodes.

General Electric Company

DA36-039 sc-90756

The purpose of this contract is the theoretical investigation, design, and development of thin film metal-dielectric active solid state electronic device with useable power gains that are relatively insensitive to temperature changes. The development of a multilayer structure that is capable of performing electronic amplification with performance characteristics approaching or surpassing other band gap model device is of prime importance in this work. The development of fabrication techniques that are compatible with the production of other circuit components which lead to reproducible active devices having near optimum characteristics is also a major objective. In line with these objectives, investigations will be initiated in two major device areas; space charge limited triodes and field effect triodes.

The field effect triode work shows that:

(a) The scribing technique for producing source-drain gaps, although capable of very small spacing and uniform line widths, has serious side effects associated with it. The diamond point damages the substrate and chips of the ruled film continue to adhere to the edges of the gap. Both effects are detrimental to completion of the device.

(b) KPR masking methods will be capable of producing source-drain gaps less than 5 microns wide.

(c) The adherence and resistivity of the insulating layer presents one of the most serious problems facing completion of the field effect device.

(d) Charge redistribution, additional charge rejection, and trap emptying may all make significant contributions to the modulation of source-drain current in the field effect triodes analyzed thus far.

The space charge limited triodes work shows that:

(a) Insulation of the grid structure (wrapping of gold lines in SiO films) by shadow-casting techniques has been successfully carried out.

(b) The deposition of fine lines by moving a fine screen has been successful, and a line density of 1000 lines/in was demonstrated.

(c) Complete space charge limited triode structures produced so far have failed either because of improper insulation or peeling of the SiO layers. Better techniques for depositing SiO must be developed.

(d) The structure adopted thus far is too complicated and time consuming to produce sufficient numbers of different samples for testing. Simpler configurations must be developed for this purpose.

The cadmium sulfide film improvement work shows that:

(a) A small quartz and glass vacuum system was successfully used to produce CdS films of controlled resistivity by evaporation methods.

(b) The dark resistivity of these films could be varied from 10 to 10^7 ohm-cm.

(c) The resistivity increases with rising substrate temperatures and decreasing evaporation rates.

1.3.8 Improving the Resolution of Iatron Direct View Storage Tubes.

ITT Corporation

NObser-87264

This program was previously reported in S.R. 71. The electrostatic microlens approach to resolution improvement appears to hold maximum promise. Analytical work including digital computer studies as well as electron optical bench analog work is being continued. Practical techniques for fabrication of complex meshes are being developed, and some measure of improvement has already been demonstrated in thick mesh tubes.

1.3.9 Planar Integration of Parts and Solid Circuits Into Thin Film Units.

Melpar, Inc.

DA36-039 sc-89109

The objective of this contract is to develop practical methods for the fabrication of compliant planar and electrical interconnections between thin film circuits, discrete parts, and solid circuits on microcircuit wafers. The advanced types of discrete parts and circuits of interest are those in the microminiature "dot" or "chip" form, which are suitable for recessing flush with the surface of the microcircuit wafer. Appropriate vacuum or other deposition techniques are to be developed for simultaneously formed interconnections between termination areas on the discrete parts and circuits and termination areas of the thin film circuitry on the microcircuit wafer.

In the development of Compliant Bridging Techniques (Task 1), the stress analysis of the bridging material indicates that (a) the linear expansion coefficients of the substrate should be high and that of the discrete part and bridging material should be low; (b) the discrete part should be thin and the substrate recess shallow; and (c) the radius of the substrate recess should be carefully adjusted to meet certain restrictions.

A commercial literature search indicated that, of the available materials suitable for bridging between the substrate and the discrete part, silicone and epoxy, or modified epoxy material, should be investigated initially. Several such materials were chosen, and tests were conducted of their ability to wet various materials. The tests showed that one of the epoxy resins (R-390) is less suitable than the others for this application. The tests further indicate that no single bridging material will produce minimum contact angles with all of the specified materials.

Consideration of the required misalignment of the dummy component has led to the conclusion that the necessary variation in gap width can be achieved by holding component and substrate-recess diameters constant and varying the position of the component within the substrate recess.

The investigation of a method of applying the bridging material to the substrate with the use of small wires has shown this to be an unsuitable method. Other techniques are under study.

For Substrate and Dummy Component Fabrication (Task 2), investigations have shown that it will be feasible to drill substrate holes and recesses simultaneously, and fabricate the dummy components to a sufficiently high tolerance.

Concerning Development of Interconnection Deposition Techniques (Task 3), there are no meaningful conclusions because of the dependency of Task 3 on the results of Tasks 1 and 2.

Finally in Task 4, Test and Evaluation, with the exception of basic program planning, effort will not start on this task until Tasks 1 and 2 are nearly complete and Task 3 is well started.

1.3.10 High Power Gaseous Electronics.

Microwave Associates, Inc.

DA36-039 sc-89161

This program was previously reported in S.R. 70. Preliminary outgassing of quartz vials at 900°C is necessary to obtain reproducible cleanup data in an electrodeless discharge. Argon cleanup is approximately independent of temperature over a -100°C to +600°C range. Three distinct cleanup regions occur: (1) an initial rapid cleanup during the first few seconds corresponding to the sorption of a monomolecular layer of gas; (2) an intermediate cleanup rate during the first twenty minutes of the discharge; (3) a slower cleanup rate region after the first twenty minutes in which cleanup proceeds at a linear rate.

Assuming that cleanup rate is proportional to the number of gas atoms present yields an expression which agrees well with the experimental results.

Spontaneous recovery of cleaned up gas is proportional to temperature. Recovery can be divided into two regions: (1) an initial rapid recovery period corresponding to the desorption of a monomolecular layer of gas; (2) a slow recovery rate period corresponding to the diffusion of gas from layers beneath the surface.

Full recovery of cleaned up gas can be achieved by heating to temperatures about 300°C greater than the temperature at which cleanup occurred.

A model which explains the cleanup phenomena after the initial rapid sorption of a monolayer of gas assumes point defect lattice damage at the wall surface. A later annealing sequence causes the sorbed atom to become trapped in the wall lattice. Continued erosion at the surface creates pits and craters which may be many hundreds of equivalent molecular layers deep. Subsequent annealing produces a honeycomb structure entrapping the cleaned up gas within the walls of the discharge container.

1.3.11 High Power Transmission Line and Associated Microwave Parts.

Microwave Associates, Inc.

NObser-85455

This program was previously reported in S.R. 70. The components are being completed for a 100 ft transmission line at S-band which can carry 15 Mw peak power and 45 kw average power. These components are being constructed so that they can be tested in a traveling wave resonant ring. For even higher power levels the above waveguide design is inadequate and evaluation of the problem leads to the recommendation that circular waveguide in the TE_{01} mode should be strongly considered.

1.3.12 Study of Electrical and Physical Characteristics of Secondary Emitting Surfaces.

University of Minnesota

AF33(616)-6239

This program was previously reported in S.R. 66. A Final Report has been written. The conclusions of the program are too extensive to be reported here. The Final Report is identified as Technical Document Report ASD-TDR-62-707, October 1962 and it has been released to ASTIA and OTS. The Abstract states:

Vacuum techniques used in this laboratory are described as well as the methods used to measure secondary electron yields, to heat small parts in a vacuum and to clean surfaces by ion bombardment. Studies of the variation of secondary yield with angle of incidence of the primary beam are described for metal and for semiconducting crystals. In the case of titanium, the influence of such factors as primary energy, orientation of the crystals, heat treatment and exposure to gas are discussed. Similar results for tungsten and germanium are compared with the case of titanium.

Measurements of the transmission and reflection secondary yield of an unbacked MgO film are presented. The data is analyzed and some important conclusions relative to present day theories of secondary emission are drawn. An experiment is described which shows that the color produced in MgO by electron bombardment extends throughout the whole crystal and studies of the influence of a cesium overlayer on the secondary yield of MgO films are reported, with particular reference to the stability of the yield under electron bombardment. The effect of exposing such films to the atmosphere is also described. The results of an investigation of the optimum oxidation conditions for Mg-Ag alloy are presented. The thickness required for full "unenhanced" yield is given as well as the dependence of the enhancement effect on thickness. Extensive studies of oxidized Mg films are summarized. Particular attention is given to new techniques being used to characterize thin insulating films. Some of the data obtained by means of these techniques are presented and analyzed.

Measurements of the secondary emission characteristics of oxidized Al films are reviewed. Recent experiments using ion-bombardment cleaning of anodized Al are also described while electron bombardment is found to have no effect on the yield of vacuum-cleaved MgO. Results to the contrary, previously reported, are explained in terms of charging of the glass envelope and the explanation is made plausible by some experiments with a tube having an internal conductive coating.

Preliminary measurements of the dissociation rate of NaCl under electron bombardment are presented. Severe disruption of the NaCl films by the electron bombardment is found to make reproducible measurements very difficult to obtain.

The results of a study of the slow electron diffraction pattern of a titanium crystal are presented. It is concluded that the diffraction apparatus developed in this laboratory is a suitable one. Preliminary results of its application to the study of an MgO surface are given. The theory of secondary electron production in metals as proposed several years ago by Dekker and van der Ziel is reconsidered. The distinction between inter-zone and intrazone transitions is made more clear and several steps in the computations are discussed and revised.

The theory of the escape of secondary electrons from polar crystals is examined with the aid of the space-momentum distribution function as governed by Boltzmann's transport equation. The computed energy and angular distributions of the external secondaries are presented and the influence of the electron affinity on the total yield is also given. The validity of the previously given theory of the angular dependence of the secondary yield is questioned. An alternative approach is suggested as well as a quantum-mechanical approach to the theory of slow electron diffraction. The relation between the diffracted beam intensities and the crystal wave functions is brought out. A theory of secondary electron emission, which takes into account the dispersion of the primary beam, is outlined.

1.3.13 Determination of Dynamics of Electron Emission
From Solids as the Result of Impact.

University of Minnesota

AF33(657)-8040

This program is related to the previous one (Item 1.3.12) reported in this Status Report. In the study of the variation of secondary emission with angle of incidence of the primary beam, it is necessary that titanium crystals be sputter-cleaned. The errors introduced when titanium is not sputter-cleaned are largely related to the magnitude of the peaks. Tungsten, however, need not be so cleaned. The asymmetrical structure observed in angular dependence studies of tungsten and germanium is caused by misalignment of the crystals and errors in the cutting of the crystal faces.

The reflection and transmission yield measurements of the unbacked gold film are quite reproducible. Similar measurements on the other film in the tube will show how these properties vary from film to film. The results of the retarding potential measurements made to date are inconclusive. Further experiments with attempts to eliminate the leakage difficulties are necessary before conclusions can be made about the energy distribution of the transmitted electrons.

The results of contact potential measurements on MgO films of different thicknesses show that in thermal equilibrium, the barrier at the contact between the MgO film and its metal substrate is less than 15 \AA in thickness. Furthermore, these results show that the thermal equilibrium electric field within the film is very small in the region 15 \AA to 1300 \AA from the substrate. Photoelectric data strongly support the postulate that electrons may be trapped in surface states that are distributed uniformly with respect to energy.

As a result of the fact that electrical conduction in alkali halides is to a large extent an ionic process, it does not appear feasible to continue the study of the dissociation of these materials. The dissociation of MgO proceeds much more slowly than the dissociation of NaCl but reproducible results can be obtained. The interpretation of these experimental measurements is in doubt at this time.

The (001) surface of a MgO crystal which has been cleaved in air is covered with two different types of structure. One is a square structure which has the MgO lattice constant. The other is similar but has a double spacing in those azimuths for which the sum of the indices is even. Argon sputtering did not clean the surface of a MgO crystal. This is indicated by the fact that it did not result in a secondary emission ratio as high as that for a vacuum-cleaved crystal and by the fact that it did not significantly change the slow electron diffraction pattern. This failure may have been due to the design of the discharge tube which prevented efficient sputtering.

It is possible to explain in a qualitative way, many of the characteristics of the structure in the variation of secondary emission from single crystals with the angle of incidence of the primary beam, by means of a model based upon the localization of both the primary electrons and the lattice electron density.

1.3.14 Noise Measurements as a Tool in Electron Device Research.

University of Minnesota

DA36-039 sc-85289

This program was previously reported in S.R. 70.

Amperex 7788 tubes have some drawbacks that make them less applicable in some low-noise wideband circuits. Some RCA nuvistor types show considerable promise as low-noise amplifiers.

Field emission tubes constructed during the eleventh reporting period show erratic noise bursts. Steps are being taken to improve the situation. Tubes and equipment for secondary emission noise measurements are being assembled.

The light emitted by cathode ray tubes shows a small noise component over and above photomultiplier noise. Methods were devised for measuring correlation between light emission noise and electron emission noise in MgO cold cathode tubes.

1.3.15 Noise in Semiconductors and Semiconductor Devices.

University of Minnesota

DA36-039 sc-85374

This program was previously reported in S.R. 71. Noise in gold-doped tunnel diodes shows $1/f$ noise at low frequencies, a plateau above full shot noise at intermediate frequencies and a drop to full shot noise in the Mc range.

Alcatron germanium field-effect transistors have high gate noise (because of the large gate leakage current) and high output noise. Both are of the $1/f$ type with the latter going as $1/f^2$ above 100 kc. These devices are unsuitable for low-noise amplifiers.

The excess noise over and above thermal noise, found in several silicon FET's at intermediate frequencies, shows the characteristics of generation-recombination noise. A likely cause of this noise could be traps in the space-charge regions under the gate.

The induced gate noise of Crystallonics FET's varies as ω^2 over a wide frequency range. The input conductance of the gate shows the same behavior. The two results combined give a noise temperature of the gate conductance that is somewhat above room temperature.

Noise spectra of silicon samples operated at elevated temperatures are of the generation-recombination type; their magnitude agrees with theory.

In thin film transistors the emitter noise can be partly suppressed. A modification of the theory of shot noise in transistors takes this effect into account.

The induced gate noise in field-effect transistors, interpreted as capacitive leakage of the channel noise, is calculated. The magnitude and the frequency dependence of this noise agrees with experiment.

The observed noise spectra in gold-doped germanium at low temperatures are explained theoretically. The theory does not assume instantaneous local space charge neutrality but takes into account space charge transients under the influence of generation-recombination processes, drift and diffusion of the carriers. Good agreement exists with experimental data.

Giant fluctuations can occur in photoconductors operating in the super-linear region of their current-light characteristics. The theory might be applicable to CdS photoconductors.

1.3.16 Metal Oxide Amplifier.

Philco Scientific Laboratory

DA36-039 sc-90715

The purpose of this work is to conduct a research and development program directed towards the development of a metal oxide amplifier with the aim of evolving an active, solid state thin film electronic device with usable power gain that is relatively insensitive to temperature changes.

A study has begun of a thin film, hot electron triode device, using tunnel emission of hot electrons into a Au film, and collection over a Au/ mixed sulfide barrier of controllable barrier height. Studies of the optical and electrical characteristics of the collector barriers show a definite relationship between the absorption edge of the films and the impedance of surface barriers on these films. Theoretical confirmation of the fact that this relationship is due to control of barrier height is being sought.

Fabrication techniques necessary for production of evaporated SiO tunnel emitters have been developed.

Evidence of hot electron collection by a mixed sulfide collector barrier has been obtained on all film triodes. The very low collection efficiencies seen in these triodes is due to collector barrier height being larger than the hot electron energy.

1.3.17 Increasing the Sensitivity of Photoemitters.

Radio Corporation of America

DA44-009 eng-4913

This program was previously reported in S.R.71. It has been shown that a demountable rubber gasketed vacuum system with a pressure of 2×10^{-7} torr was unsuitable for photocathode formation. A tube was designed for multi-alkali cathode formation. It has been used for formation of Na₃Sb and K₃Sb. Na₃Sb and K₃Sb photocathodes have been produced with sensitivity comparable to that of the best prepared by conventional processing.

Plots of photoemission vs. time for the deposition of sodium or potassium on antimony show structure which may be related to the kinetics of compound formation and under similar conditions, cathode formation appears to be reproducible.

P-n junctions have been produced by diffusion of arsenic in germanium which are suitable for testing as field induced photoemitters and the diffusion constant of arsenic in germanium has been determined over the range of temperatures 600°C to 800°C.

Light emission has been observed from reverse biased germanium p-n junctions with a microscope and with an infrared pickup tube.

An electron gun suitable for low energy electron diffraction has been developed.

Further examination of photocathode structures has shown beyond doubt that the sensitive Ag-Bi-Cs-O cathode results from the formation of a phase with non-cubic symmetry.

1.3.18 Applied Research in Microminiature Field Emission Tubes.

Stanford Research Institute

DA36-039 sc-84526

This program was previously reported in S.R. 72. A Final Report has been written. According to data obtained from field-plotting, micron-sized field emission triodes are characterized by amplification factors comparable to those of conventional, receiving-type triodes and by values of mutual conductance and dynamic plate resistance which are, respectively, lower and higher. Power gains of 10 or more appear to be realizable. Cathodes consisting of one or more small protuberances on the cathode plane are superior in at least two respects to a single cathode having a radius of curvature of 1000 Å. They tend to collimate the emission, thus reducing grid current, and being small, the field at their tips is enhanced more than that of the larger emitter.

Tubes were simulated in a demountable ultra-vacuum chamber equipped with mechanical manipulators capable of moving emitters about .1-in in any direction, the motion being controllable to 200 Å or less. Emitters formed by conventional electrolytic polishing techniques were moved into control-grid holes having diameters ranging from 17 μ to about 1.5 μ. Emitter and grid currents, as functions of grid voltage, were measured. These data, combined with those deduced from field plots, indicate that operation of micron-size tubes at 100 V or less requires emitter radii of 300 Å or less if 1 μA is to be drawn from each emitter.

It was found that emission from exploded emitters could be restored by making and breaking electrical contact between them and the grid. Evidence indicates that this resulted in the production of about 100 Å radius protuberances on the relatively blunt emitter stub. These so-called special emitters were moved under grid holes ranging in diameter from 2 μ to 0.8 μ, and the grid-control characteristics were observed. It was concluded from the data obtained that, in the micron-tube dimensional range, the special emitters were superior to those conventionally formed, from the standpoints of grid voltage requirements and of grid currents produced.

Special emitters were moved close to molybdenum sheets and films of differing thickness to determine the limits of anode power and current density. Limiting values were calculated from measurement of spacing, voltage, and current when the emitters exploded. Power and current densities exceeding 10^8 W/cm² and 10^7 A/cm² were calculated when

the anode was a 3-mil-thick sheet of molybdenum. A 2000 Å molybdenum film on a sapphire substrate yielded power and current densities exceeding 10^7 W/cm² and 10^5 A/cm², respectively. This is particularly significant from the standpoint of micron-size tube design.

It is concluded that emitters, closely spaced under a counter-electrode (anode), explode because of increase of gas pressure in the cathode-anode interspace. The gas is released from the bombarded area of the anode and consists of contaminants, or of vaporized anode material, or both. Actual micron-size tubes made by present techniques are expected to be relatively free from contaminants and material instabilities which are potential threats to cathode life.

The tube-simulation experiments have demonstrated the feasibility of micron-size tube concepts — at least to the extent that field emission can be obtained and controlled at grid voltages of 100 V or less — and have shown that useful power gains can be realized.

Apparatus and techniques for construction of micron-size devices are being developed. Fundamental processes are reactive depositions of alternate layers of conductors and insulators, masked and machined in prescribed patterns with the aid of electron-activated chemistry. Essential to the processes is an ultra-high vacuum chamber, equipped for the manipulation of chemical vials and of substrates in which devices are made. Advances in state-of-the-art technology are mandatory. Noteworthy among the advances made are: (1) attainment of a vacuum of less than 10^{-11} torr in a 56-liter chamber in less than two hours; (2) the use of boron-oxide as a vacuum seal; (3) development of a mass spectrometer with a range of 1-1000 atomic mass units, resolution of 1 in 400 atomic mass units, fractional-second scanning speed and with a bakeable analyzer unit having a volume of less than 10 cu in; (4) machining of fused quartz and alumina parts for a high-resolution electron-lens system to fractional-micron tolerances; (5) development of ceramic-to-metal brazes to withstand 900°C temperatures in vacuum; (6) the demonstration of micromachining.

1.3.19 Research on Dielectrics for Microwave Devices.

Stanford Research Institute

DA36-039 sc-90856

Failures of dielectric materials used in microwave electronic devices have been a source of great concern. The goal of this program is to study these materials in terms of their properties and the factors that control them. To achieve this goal it was decided that it was necessary to prepare dielectric materials in their most pure form and then change them by controlled modification of composition and structure. Tracing the effects of these modifications when guided by a proper theoretical model of the material will lead to a better understanding of the factors that influence the behavior of the dielectric materials, and of ways in which this behavior can be controlled.

The program has been divided into three phases: (1) a study of the electronic processes that occur in the material and how they are influenced by the electronic structure, impurities, and defects; (2) preparation of thin films of the dielectric material so that they will represent highly controlled forms of the dielectric for conducting experimental studies of the factors influencing their behavior; and (3) a study of the effect of ionization of residual gases in voids of the dielectric on the breakdown of the material.

In the first quarter a study of the theories of breakdown of dielectrics was initiated. These theories are concerned with the effect of applied fields on free electrons and the interaction of the free electrons with the lattice of the material or other free electrons. The effect of thermal energy imparted to the free electrons is also considered. If there is an excess of energy over that lost to the lattice, breakdown can occur.

The process of growing the films of aluminum oxide is being studied in terms of the reactions most likely to provide a coherent and controllable composition. These processes can include oxidation of the purified base metal or reactive deposition of the material from the gas phase.

For either process an ultra high vacuum system with facilities for identification of components is necessary. This system is in the process of construction. It will include a quadrupole mass spectrometer and a double wall vacuum chamber capable of achieving pressures in the range of 10^{-10} to 10^{-12} Torr.

One method of examining the prepared films for structure is that of the field ionization microscope. Studies are being conducted to determine the most advantageous method of constructing this device.

There is a possibility that high rf field can induce ionization of gases within the voids of ceramic dielectrics. The ionization process can lead to thermal stresses in the region of the voids and consequently to failure of the material. A study of the probability of ionization of residual gas in voids of window ceramics indicates that there is a high probability of this occurring in microwave fields when voids are large (0.010 in and larger). There is some doubt whether the breakdown can occur for smaller voids. An experiment has been designed to verify this hypothesis.

1. 3. 20 Thin Films Formed by Electrochemical Reactions.

Texas Instruments, Inc.

DA36-039 sc-90745

The purpose of this study is the development of techniques for fabricating thin conductive, resistive, and dielectric films, by complete or partial anodic oxidation of selected deposits of the metals tantalum and niobium. Emphasis in the initial phase of the study should be placed on the necessary techniques and process controls aimed at producing the capacitive and resistive films. The techniques developed should permit the formation of patterns of high resolution, but

must be readily and economically adaptable to the mass production of interconnected microelectronic parts. These parts should have reliability and tolerance limits comparable to levels currently attainable with vacuum deposition methods.

Work closely related to this project is being conducted under Contract DA36-039 sc-87305 at General Telephone and Electronics Laboratories (reported in S.R. 69, Item 1.3.3).

Certain process procedures (i.e., substrate cleaning, avoidance of film abrasion, KMER removal, etc.) were shown to be effective in increasing tantalum film capacitor yields.

Tissuemat wax was found to provide adequate breakdown strength as an anodizing stop-off material.

Variations in electrical evaluation of sputtered tantalum films necessitate sampling evaluation of sputtered material prior to use as circuit material.

Tantalum resistor temperature coefficients show low average values and substantial spread over the range -55°C to $+165^{\circ}\text{C}$ for 18.6 ohms per square samples. 150 ohms per square samples and 300 ohms per square samples tend to negative average values, and with substantial spread between identical samples.

In a brief loading test, coating inhibited heat dissipation in 50-kilohm tantalum resistors at 125°C and caused failure to occur at lower applied voltages than for uncoated samples.

10,000-ohm tantalum resistor temperature profiles on back-side of the alumina substrate show 51°C "hotspot" temperatures for 175-mw loading on a 3-resistor substrate at 25°C ambient.

Both tantalum and niobium film resistors show very low excess noise levels prior to anodizing, with only a slight increase in level after anodizing.

Niobium component fabrication was hampered by problems encountered in sputtering. These problems will continue to be attacked.

1.3.21 PEM: Polyoptic Sealing of Hydrogen Thyatron Tubes.

Tung-Sol Electric, Inc.

DA36-039 sc-81289

This program was previously reported in S.R. 70. An investigation is now being conducted to find new and better ways of lapping, polishing and cleaning the glassware used in polyoptic tubes. New lap fabricating materials are under construction, the button to bulb lapping technique is being employed, and a modified glassware cleaning technique is now in use. The reasons for these studies are: (1) to obtain a better polyoptic fit between the button and bulb before they are evacuated. This will result in a higher vacuum pressure prior to rf hot ring sealing; (2) it will eliminate large quantities of air present in the tube at elevated baking temperatures, before rf hot ring sealing; (3) a shorter time needed to perform the necessary lapping and polishing steps.

Maintaining high vacuum pressures during the entire pumping and sealing process has become an area of particular importance in the work done recently.

Of 75 tubes which have been on life test, 2 still remain. A new batch of 40 tubes are being prepared for life test comparison studies. This includes 20 polyoptic tubes (hot ring) and 20 flame sealed. Experimental variables are being kept to a minimum so that the value of the polyoptic seal itself can be compared and evaluated with the flame seal.

1.3.22 Active Thin Film Circuit Functions.

Union Carbide Corporation

DA36-039 sc-90734

Although the project is still in its early stages, a number of observations may be made regarding the information already obtained. A detailed and critical review of existing literature is sometimes unexpectedly instructive. This has proven to be true of the present effort. It had been widely believed that epitaxial crystal growth was a highly specialized situation involving a close match of lattice dimensions and a narrow range of deposition temperatures. Viewed in the broader perspective of the present literature survey, the situation is almost diametrically opposed. The recent literature actually shows that epitaxial growth under proper clean conditions is the rule rather than the exception. The poorly controlled factor in early work apparently was the surface itself. The methods used to produce clean surfaces previously were ineffective and crystal growth was nucleated at many sites and with random orientation. If the surface is truly clean, the crystal growth proceeds easily in an epitaxial manner providing the temperature of the substrate is sufficiently high to allow a free surface mobility of the depositing atoms. This temperature also is not specific as had been believed but is dependent on the arrival rate of the depositing material. This present study of the literature is leading to a theory of epitaxial growth that is concerned with the energetics of the mechanism of orientation and which will cast new light on this important problem. The model that is being considered has qualitatively arrived at new criteria for orientation of epitaxial growth that are consistent with all the information presently available. An effort is being made to make this theoretical picture quantitative.

Possibly more important for the goals of the project is the recognition, as a result of this literature survey, that an effort should be made to achieve "anti-epitaxial" growth; that is, if single crystal growth is to be achieved on a polycrystalline substrate, it should be done under circumstances in which the substrate has no influence on the growing crystal. The conditions of surface cleanliness to avoid multinuclear growth are the same as in true epitaxial growth. These requirements imply a substrate that does not have a tendency for the formation of strong chemical bonds with the deposit or at least a "non-wetting" combination with small interaction.

This thinking may be correlated with the experimental results. The data presented show that epitaxial single crystal growth of silicon on silicon can be achieved by three different methods, silane or trichlorosilane decomposition, and silicon evaporation. The conditions for all are similar, an oxide or disturbance free surface to avoid multiple nucleation, and a sufficiently high surface temperature to allow rapid surface migration and so regular crystal growth. From this study there is little to indicate a strong preference between the deposition methods although each has special features that may be advantageous in a particular situation. Good crystal growth from the chemical deposition was obtained for essentially the same substrate temperature, ca. 1200°C. The evaporated deposits with its slower growth rate could be successful at lower temperatures.

The data already show that routine deposition procedures are not likely to produce single crystals on polycrystalline substrates. This, of course, is not surprising and in fact the work described was designed to establish conditions for single crystal growth in the existing apparatus. These conditions can then be duplicated in more complex situations where single crystal growth could be hoped for.

Other factors such as the difference in thermal expansion have been found to be important and must be provided for, but these are supplementary and soluble. The major problem seems to reduce to the production of a surface of sufficient cleanliness and uniformity that polycrystalline growth is not nucleated and whose other physical properties are compatible with the growing crystal. It is still likely that "seeding" in some form will be required to give a single crystal growth and this approach will be considered.

1.3.23 Interconnection of Functional Electronic Blocks.

United Aircraft Corporation

AF33(657)-8790

This program is directed toward the development of production processes and techniques, and the establishment of unbalanced production line for the interconnection of FEB's (Functional Electronic Blocks). The preliminary requirements for the hermetic modular interconnection - packaging system have been defined and a prototype unit fabricated. (See also reports in S.R. 67, 71, 72 under DA36-039 sc-89176)

In the first phase of this effort analytical appraisal of the characteristics of presently available FEB's has been nearly completed. All the companies which reportedly are engaged in the fabrication of FEB's were contacted by mail to secure information on the electrical as well as morphological characteristics of presently available solid state blocks. In addition, a few major companies were visited to gain further insight on their future plans. The majority of the FEB's commercially available are for digital applications; however, there appears to be considerable effort under way to develop solid state blocks for analog applications.

Presently, FEB's are packaged in either hermetic cans such as the TO-5 and TO-18, or in flat form containers such as the Texas Instruments package; however, it appears that the latter type package with standardized dimensions and geometries will be used extensively in a not too distant future. This trend is strongly encouraged by the Air Force.

The data accumulated to date have been used to design and build a prototype modular interconnection - packaging system. The latter is a grooved monolithic ceramic wafer within which the FEB's are to be attached to optimize dissipation of thermal energy. Communication between FEB's, auxiliary passive elements, if required, and the outside world is to be provided by a horizontal and vertical interconnection matrix. The hermetic system is directed toward the use of uncased FEB's; however, it makes provisions for presently available hermetically packaged solid state blocks.

Work has been started on the refinement and production-adaptation and gas plating, vacuum deposition, electron beam processes and associated techniques required for the fabrication of the basic substrate wafer with the horizontal and vertical interconnection matrix.

1.3.24 Scan-Conversion Storage Tube Based Upon the Permachon.

Westinghouse Electric Corp. DA36-039 sc-85051

This program was previously reported in S.R. 70. The main effort during the ninth quarterly period was switched to the fiber-optics type of target, although two EBIC-type tubes were completed to finish a series of experiments started during the previous quarter.

In the fiber-optics target study a problem was encountered concerning the transparent conductive coatings that must be applied to both sides of the fiber-optics plate to provide electrical contact to the phosphor and Permachon photoconductor. The problem stems from the inability to apply a stannic-oxide coating with reproducible resistance characteristics. The resistance of most of the stannic-oxide coatings has been too high. The results of experiments performed on this problem are as yet inconclusive, and further work will be done in this area.

The fiber-optics mount development was successfully completed and will be used during the remainder of the contract to hold 1 in diameter targets.

Tests were made to measure target capacitance and erase characteristics. Only one of each of these measurements was made, and although the resulting data are encouraging, further tests must be performed before definite conclusions can be drawn.

Additional test equipment has been added to facilitate making the additional tests required.

1.3.25 Hollow-Cathode Negative-Grid Tube for VHF-UHF Applications.

Westinghouse Electric Corp. DA36-039 sc-90845

This experimental research study is directed toward investigating the feasibility of incorporating hollow-cathode structures in negative-grid triodes and tetrodes. Emphasis will be placed on utilizing the high-peak-current capability of this type cathode to extend the high-frequency performance of these types of tubes. The study shall consist primarily of the construction of feasibility models of various designs. So far, several triodes have been built. The resulting tubes show an approximately linear relationship between grid voltage and plate current. The g_m , however, is low.

1.3.26 High Gain Transmission Secondary Emission Films.

Westinghouse Electric Corp. DA44-009 eng-4858

This program was previously reported in S.R. 70. Although the correlation of evaporation parameters to structure to electrical behavior achieved thus far can hardly be considered complete, it is sufficient to permit a quantitative description of the evaporation techniques required to make high gain dynodes. The primary question left unanswered is whether or not densities of less than 1% improve the gain characteristic. In order to achieve such low densities, it seems necessary to change the evaporation geometry. Due to time limitations, this question will be left temporarily unanswered. The rather limited range of film thicknesses studied thus far is adequate for several reasons. Practical limitations are imposed on both the maximum and minimum film thickness; very thick films require excessively high primary energies while very thin films are capable of intercepting only a small fraction of the primary electrons. In addition, there are indications that films thicker than those presently used would show reduced gain without an increase in breakdown voltage.

Thus it seems fairly certain that the optimum electrical performance can be achieved from a film of approximately 1.5% density and 25 μ thickness. If the standard boat, placed 2-in from the substrate is used, such a structure can be obtained by evaporating 25 mg at a uniform rate of 2.5 mg/sec in an argon atmosphere of 2 mm Hg. A dynode thus made can be expected to yield a maximum TSE gain of between 30 and 100, generally 60, at a maximum collector voltage of 100 to 500 V for a 0.25-in dynode to collector spacing.

1.3.27 Inorganic Binders for "C" Cores.

Westinghouse Electric Corp.

NObsr-85304

The purpose of this program was to expand the developments of inorganic binders for grain-oriented silicon-steel initiated in a previous program under NObsr-77578. Since it was possible to utilize most of the facilities and application processes which were pioneered in the previous program, less funds were required and more time was available for a more extensive development and evaluation of the binder. An additional step in this direction was made by the use of a new core construction method developed with Westinghouse funds.

The general objective was the development and evaluation of an inorganic glassy binder for grain-oriented silicon-steel wound-cut cores suitable for operation over the temperature range -55°C to $+600^{\circ}\text{C}$.

An inorganic glassy binder and a method for its application to a wound-cut type C core were developed. The binder, having a composition and the properties of glass, served as an electrical insulator as well as the adhesive. Sample cores were constructed by fusing a very thin layer of the binder to the surfaces of grain-oriented silicon-steel strips and winding the composite until the required build-up was obtained. During the requisite stress relief anneal, a laminar bond between the adjacent binder-coated turns was accomplished. A total of 48 sample cores were constructed for the evaluation of the binder. Sample cores constructed with two steel thicknesses had space factors, net steel weights, and mean magnetic paths nominally equivalent to commercial cores. These cores were evaluated for core loss and excitation at various flux densities at room temperature, 400°C , 600°C , and -55°C . Effects of heat aging on their mechanical and electrical properties were determined. The core loss and excitation values at 15 kilogausses were less than the published rejection limits for equivalent commercial cores.

2. Publications.

2.1 Some Semiconductor Surface State Studies.

National Bureau of Standards

Report 7746

This alliterative title is Scientific Report 3 to Air Force Cambridge Research Laboratories under PRO-62-206. The report presents a new method of studying the surface states of silicon. The first part describes the basic experimental phenomena and presents explanations and interpretation. The second part gives several possible applications of the phenomena as a two-terminal device. The third part consists of supplementary information that is intended to bring the reader up to the same technological position as the authors. The work essentially involves applying porous graphite contacts to p-type silicon and exposing the samples to various inversion-layer producing gaseous ambients. A voltage pulse is applied to the sample and the resulting

current pulse is a measure of the density of charge states. From such data it was found that the number of water-vapor-induced surface states on p-type silicon was $5 \times 10^{12}/\text{cm}^2$. For any sample this value was reduced ~50% by using ammonia instead of water vapor. Tests using widely differing electrode particle sizes resulted in no change in the measured density of states. By applying a small dc bias (~1V at <1 mA) to control the surface potential it is possible to continuously extend the current envelope or reduce it to a small capacitive spike. The total charge, at fixed bias, is a constant, independent of applied voltage amplitude. The major advantage of the device possibilities lies in the magnitude of the charges which can be stored and the ease with which it can be controlled by small bias currents.

2.2 How Failure Indicators Can Improve Reliability.

AF Cambridge Research Labs

June 1962

AD 285793 This 12-page report, AFCRL 62-361, by W. B. Bishop, states in its Abstract: "The fact that a failure has occurred usually can be detected without a specifically designed failure indicator. In a complex device, however, many types of failure indicators can be helpful in determining the source of trouble. If reliability is defined to be a measure of the percentage of time a device is operable, then proper design and use of failure indicators can improve reliability. The relationship is shown between the statistical theory of failure indicators and other parts of the reliability literature and develops some of the principles which should be followed in the design and use of failure indicators. As might be expected, a number of these principles were followed by good maintenance men for many years."

3. Annual Index for 1962: Status Reports 67-72 Inclusive.

3.1 1962 Annual Index of Government-Sponsored Projects.

The following table lists the government-sponsored projects which were reported in the past year in the Status Reports. The reference column shows Status Report number-page number.

<u>Company</u>	<u>Identification or Contract Number</u>	<u>References</u>
Aerovox Corp.	DA36-039 sc-87444	67-1, 70-1
American Electronics Lab.	DA36-039 sc-78349	72-1
	DA36-039 sc-87452	69-12
Amphenol-Borg Electronics	DA36-039 sc-87467	67-1, 70-1
Battelle Memorial Institute	ARPA SD-80	67-22
	DA36-039 sc-85294	71-20

<u>Company</u>	<u>Identification or Contract Number</u>	<u>References</u>
Bell Telephone Labs.	DA36-039 sc-87234	71-1
Richard D. Brew Co.	DA36-039 sc-85288	70-2
Burndy Corp.	DA36-039 sc-85964	70-3
CBS Laboratories	AF33(616)-8509	69-12
	DA36-039 sc-87379	71-2
	DA36-039 sc-88900	70-25
Clevite Corp.	AF30(602)-2556	71-21
	DA36-039 sc-85346	67-2, 69-1
Columbia Technical Corp.	NObsr-77562	69-2
Contronics, Inc.	NObsr-85462	72-1
Cornell-Dubilier, Inc.	DA36-039 sc-85955	69-2
	DA36-039 sc-89132	67-3, 70-4
Corning Glass Works	DA36-039 sc-89101	72-2
	NObsr-87385	72-16
CTS Corporation	DA36-039 sc-85976	67-2, 70-3
Daystrom, Inc.	NObsr-77548	69-3, 72-22
Edgerton, Germeshausen & Grier, Inc.	DA36-039 sc-85338	67-22, 71-24
	DA36-039 sc-87306	70-24
Eitel-McCullough, Inc.	AF33(600)-36699	68-1
Electro-Optical Systems	AF33(616)-7784	67-23
Electronic Communications	AF19(604)-5475	70-25
General Dynamics	DA36-039 sc-88908	72-2
	DA36-039 sc-89196	72-16
	NObsr-81208	67-24, 70-27
General Electric Co.	AF19(604)-5557	70-24, 71-21
	AF33(600)-32011	68-1
	AF33(616)-7183	67-4
	AF33(616)-8096	67-5, 68-2, 71-2
	DA36-039 sc-75070	67-6, 69-3, 71-4
	DA36-039 sc-78115	67-19
	DA36-039 sc-78938	70-5
	DA36-039 sc-85047	69-4, 72-4

<u>Company</u>	<u>Identification or Contract Number</u>	<u>Reference</u>
General Electric Co. (Cont'd.)	DA36-039 sc-85049	69-4, 71-4
	DA36-039 sc-85062	67-24
	DA36-039 sc-85366	67-6, 72-4
	DA36-039 sc-85953	67-7, 69-5
	DA36-039 sc-85965	70-6
	DA36-039 sc-85973	68-3
	DA36-039 sc-87253	67-20, 68-9, 70-23, 72-17
	DA36-039 sc-87289	67-7, 69-5, 71-5
	DA36-039 sc-87443	67-8, 69-5, 72-6
	DA36-039 sc-87466	70-7
	DA36-039 sc-88951	71-5
	DA36-039 sc-88964	71-5
	DA36-039 sc-89193	72-6
	DA36-039 sc-90743	72-6
	NObsr-81225	67-24, 68-12, 71-24
	NObsr-81369	69-6
	NObsr-85470	69-7, 72-5
General Telephone & Electronics Labs.	AF19(604)-5512	67-25
	AF19(604)-7286	68-12, 71-26
	DA36-039 sc-87305	69-13
Gulton Industries	AF19(604)-5730	68-13
Hoffman Electronics	DA36-039 sc-87276	70-8
	DA36-039 sc-87420	70-27
Horizons, Inc.	DA36-039 sc-89203	72-22
Hughes Aircraft Co.	AF33(616)-7563	69-15
	AF33(657)-7789	70-28
	DA36-039 sc-85354	68-13
	DA36-039 sc-87221	72-23
	NObsr-81198	67-25, 69-15
	NObsr-85296	69-13
International Business Machines Corp.	DA36-039 sc-85395	67-21, 69-11, 70-23, 71-21
	DA36-039 sc-87247	68-14, 72-24
Illinois Inst. of Technology	DA36-039 sc-78342	69-16
International Resistance Co.	DA36-039 sc-78941	71-6
	DA36-039 sc-81283	68-4, 70-9
	NObsr-85292	67-8, 68-4

<u>Company</u>	<u>Identification or Contract Number</u>	<u>Reference</u>
International Telephone & Telegraph Co.	DA36-039 sc-78953 DA36-039 sc-85967 NObsr-87264	68-4 67-8, 70-9 71-27
Johns Hopkins University	Nord-7386	70-29
Walter Kidde & Co.	DA36-039 sc-85240	68-5
Kuthe Laboratories	DA36-039 sc-85985	71-7
Linden Laboratories	DA36-039 sc-78912	67-25, 68-16
Linfield Research Institute	AF30(602)-2157 DA36-039 sc-85368 Nord-7386	71-27 70-30, 71-28 71-7
Litton Electron Tube	DA36-039 sc-87313 DA36-039 sc-87361	67-26, 69-16, 72-25 69-16
Litton Industries	NObsr-77568	70-40
Melabs, Inc.	DA36-039 sc-87412	70-31
Merrimac R&D Labs.	AF19(604)-7288	67-27
University of Michigan	AF33(616)-7542 NObsr-81403	71-30 70-10
Microwave Associates Inc.	AF30(602)-2545 DA36-039 sc-85316 DA36-039 sc-85987 DA36-039 sc-87359 DA36-039 sc-87385 DA36-039 sc-87391 DA36-039 sc-87422 NObsr-77586 NObsr-85190 NObsr-85455 NObsr-87291	70-21 72-7 72-8 69-8 69-17 70-32 69-8 68-6 69-18, 71-31 69-19, 70-32 70-10
Microwave Electronics	Nonr-3470(00)x	67-9
University of Minnesota	AF19(604)-3890 AF33(616)-6455 DA36-039 sc-85289 DA36-039 sc-85374	67-27 69-19 67-29, 70-33 67-29, 68-16, 71-31
Mitronics, Inc.	DA36-039 sc-87351	67-30, 68-17, 70-34

<u>Company</u>	<u>Identification or Contract Number</u>	<u>Reference</u>
Motorola, Inc.	AF33(616)-8276	69-21
	DA36-039 sc-85975	67-10, 70-11
	DA36-039 sc-87235	70-20
	NObsr-77618	67-31
	NObsr-81244	71-11
	NObsr-85397	67-10
	NObsr-87438	72-9
National Cash Register	AF33(657)-8985	72-26
	DA44-009 eng-5085	72-26
North American Aviation	MIPR-R-62-16sc-00-93	71-22
Nuclear Corp. of America	DA36-039 sc-87328	70-34
	DA36-039 sc-87392	69-21
Ohio State University	AF33(616)-8391	68-18, 69-23
Pacific Semiconductor	DA36-039 sc-85255	71-12
	DA36-039 sc-87342	68-6
Philco Corp.	DA36-039 sc-85345	68-19, 71-32
	DA36-039 sc-88891	68-19, 71-34
	NObsr-81189	67-31
Radio Corp. of America	AF19(604)-6152	67-32, 71-34
	AF19(604)-8018	69-23
	AF30(602)-2365	68-7
	AF33(600)-37267	70-11
	AF33(600)-37268	70-12, 72-10
	AF33(616)-6563	67-33
	AF33(616)-7696	67-33, 72-26
	AF33(657)-7939	70-12
	DA36-039 sc-72709	68-10, 69-11
	DA36-039 sc-75968	71-14
	DA36-039 sc-78032	67-12
	DA36-039 sc-81285	69-9
	DA36-039 sc-85045	69-9, 72-10
	DA36-039 sc-85253	70-13
	DA36-039 sc-85968	70-15
	DA36-039 sc-87388	68-20, 71-35
	DA36-039 sc-87390	67-34, 71-35
	DA36-039 sc-87393	67-34, 70-34
	DA36-039 sc-87415	68-7, 70-15
	DA36-039 sc-89079	72-10
	DA36-039 sc-89121	71-23
	DA44-009 eng-4590	67-35
	DA44-009 eng-4913	71-36

<u>Company</u>	<u>Identification or Contract Number</u>	<u>Reference</u>
Radio Corp. of America (cont'd.)	NObsr-77637	68-20
	NObsr-77644	70-16
	NObsr-81322	71-15
	NObsr-81478	71-16
	NObsr-85371	68-8
Rauland Corp.	NObsr-87395	71-16
Raytheon Co.	AF33(616)-7378	69-23
	AF33(616)-7394	67-22, 70-21
	DA36-039 sc-87369	67-36
	NObsr-85323	67-12
Ronson Metals Corp.	AF19(604)-8430	67-36, 71-36
Servomechanisms, Inc.	DA36-039 sc-87316	68-21, 71-37
S-F-D Laboratories	AF33(616)-7054	67-12
	AF33(616)-8030	70-16
	DA36-039 sc-87347	67-14, 70-17, 72-11
Sperry Gyroscope Co.	AF30(602)-2371	71-37
	AF30(602)-2428	67-37, 70-35
	AF30(602)-2495	67-38, 69-24
	DA36-039 sc-87389	71-23
Sprague Electric Co.	DA36-039 sc-85966	70-17, 72-11
	DA36-039 sc-86721	72-19
	DA36-039 sc-90705	72-20
	NObsr-77598	72-12
Stanford Research Institute	DA36-039 sc-89150	71-39
	DA36-039 sc-84526	67-38, 71-38, 72-27
Stevens Inst. of Technology	DA36-039 sc-89148	72-20
Syracuse University	AF30(602)-2177	72-20
Sylvania Electric Products (General Telephone & Electronics)	AF33(600)-37967	67-15
	DA36-039 sc-85377	69-25
	NObsr-81552	68-8, 69-10, 71-17
	NObsr-85431	69-25
Technical Research Group	DA36-039 sc-88979	70-18
Texas Instruments, Inc.	AF33(616)-7085	67-15
	NObsr-85406	68-8, 70-19
	NObsr-85424	67-38

<u>Company</u>	<u>Identification or Contract Number</u>	<u>Reference</u>
Tung-Sol Electric, Inc.	DA36-039 sc-81289	70-36
	DA36-039 sc-85061	67-16, 70-19
	DA36-039 sc-85120	69-26
	DA36-039 sc-85984	71-17
	NObsr-81287	69-10
Union Carbide Corp.	NObsr-87478	72-28
United Aircraft Co.	DA36-039 sc-87301	67-17, 71-17, 72-14
	DA36-039 sc-89176	72-14
Varian Associates	AF33(616)-6590	67-39
Watkins-Johnson Co.	DA36-039 sc-87396	71-18
	Nonr-3020(00)	68-22
Western Electric Co.	DA36-039 sc-81268	71-19
Westinghouse Electric Corp.	AF30(602)-2558	68-11
	AF33(600)-38881	67-17
	AF33(616)-3254	70-37
	AF33(616)-6422	70-38
	AF33(616)-7723	71-40
	AF33(657)-8675	72-28
	DA36-039 sc-85051	68-22, 70-38
	DA36-039 sc-85944	70-20
	DA36-039 sc-87397	68-9
	DA36-039 sc-87404	67-18, 71-20
	DA44-009 eng-4531	72-15
	DA44-009 eng-4858	70-39
	NObsr-77582	68-23
	NObsr-81380	69-27

3.2 1962 Annual Index of Tube or Semiconductor Device Types.

The following index lists those tubes or semiconductor devices which appeared for any reason in Status Reports 67-72 inclusive. Each reference shows a code letter () indicating the general nature of the reference. As described in 3.1, the Reference column indicates Status Report number-page number.

<u>Code Number</u>	<u>Reference</u>
(D)	Development
(E)	Evaluation
(L)	Life Test
(P)	Production
(R)	Reliability Studies
(X)	Radiation Effects
(Z)	Miscellaneous

<u>Code Number</u>		<u>Reference</u>
A 15203	(D)	70-13
A 15274	(D)	71-16
A 15330	(D)	71-16
C36D	(D)	70-17
C 74367	(D)	70-16
FW-202	(P)	67-9
GL4683PZB	(P)	68-3
PD-267	(Z)	68-21
PMT-014	(Z)	68-21
PT 531	(R)	71-12
QKS 1020/21	(D)	67-12
SN 2146	(E)	67-15
SN2967/8212	(D-P)	68-8,, 69-10,, 71-17
SN2968/8213	(D-P)	68-8, 69-10, 71-17
VA-130	(D)	67-39
WX-4222	(D)	67-17
XD 85AA	(D)	69-5
XD 26H	(L)	68-12
XM 483	(D)	70-11
XP 76D	(D)	67-6
A 4751	(D)	70-6
Z 4808	(D)	70-7
Z 4809	(D)	70-7
Z 5161	(D)	68-1
Z 5278	(D)	69-4
2N384	(Z)	69-25
2N535	(Z)	68-17
2N697	(Z)	67-30, 69-25, 70-34
2N1480	(L)	68-11, 69-12
2N1484	(L)	68-10, 69-12
2N1488	(L)	68-11, 69-12
2N2049	(Z)	68-17
10KP7	(Z)	71-16
5814	(L)	68-20
5896	(L)	67-20
6005	(L)	68-20
6286	(L)	67-20
6299	(Z)	67-7
6861	(Z)	70-34
6884	(D)	67-12
7788	(Z)	70-34
7801	(Z)	67-12
8191	(D)	70-19
8192	(D)	70-19